NITRALLOY STEEL AND NITRIDING.

Paper presented to the Institution, Glasgow Section, by J. McCrone.

Introductory.

IT is common knowledge that a great many requirements occur in engineering production for parts possessing a high degree of hardness, and its accompanying high resistance to wear. From consideration of other necessary qualities, such as strength and ductility, it is not desired that parts should exhibit great hardness throughout their entire mass ; hence there has been built up through many generations a wide technique in the art of producing articles, principally of iron and steel, having their property of hardness confined to a region at—and close to—the wearing surfaces, while retaining a measure of strength in the main body of material. Development of means for achieving this two-fold result has made a very noteworthy advance in recent times, and the object of this paper is to describe a particular material and process, by the use of which hardness *and* strength are attained to a degree not realised by other and older methods, and to review some applications to the needs of modern engineering products.

Previous Methods.

It may be useful first of all to mention the methods of surface-hardening in common use hitherto. These may be enumerated briefly as : (*a*) *Rapid Cooling* from high temperature, which operates by modifying the grain structure of the metal, as in the production of chilled castings. (*b*) *Carburising*, that is, adding carbon to the composition of the material, followed by quenching from a high temperature. This method is very widely used for the case-hardening of mild steels and alloy steels.

The carbon is furnished by a mixture of highly carbonaceous materials packed around the articles in a container, which is brought up to high temperature, usually 900 degrees C. in a furnace, fired either by gas, oil, or solid fuel. In usual practice, the carburising temperature is reached in three hours, and maintained for five hours, the resulting depth of hardening being about .090 inch, say $\frac{3}{32}$ inch. The coarse grain structure must thereafter be refined by reheating to between 880 degrees and 900 degrees C. followed by quenching ; this operation, however, only refines the core. A second reheating, and quenching from about 760 degrees C., is

required to refine and improve the strength of the case. In order to limit the tendency to brittleness, carburising is carried out on low carbon steels, usually 0.2 per cent. carbon, the resulting case analysing about 0.9 per cent. ; if the latter figure is exceeded, there is great liability to quenching and grinding cracking. Due to the high treatment temperature, there is considerable distortion of the articles, which must be rectified by subsequent grinding.

Where the duty of the parts is not unduly arduous, carburising gives very good results for general work, particularly if the parts are of simple character and not large. On the other hand, if the thickness or diameter is at all large, the rate of cooling of the core is not rapid enough to produce the best results. Improved mechanical properties are obtained by using alloy steels containing either, nickel only (two to five per cent.) or nickel and chromium. Such steels are, of course, more expensive but require only one reheating.

Cyanide hardeninq also falls to be mentioned. Much development work has been done on this process, but it has its limitations, a serious one being the poisonous nature of the fumes, hence it does not enjoy wide favour.

Nitrogen-Hardening.

The newer development referred to arises from the discovery, about the year 1920, after long research by Dr. Fry, in Germany, that a single heating treatment in an atmosphere of ammonia at its dissociation temperature, which is an unusually low temperature for the treatment of steel, produced on steel of a particular composition an abnormally hardened surface. Further experimental work by Dr. Fry established the composition required to produce the best results, also the procedure to be followed in order to achieve them.

In the matter of commercial development, however, much of the credit is due to French interests, who hold the principal control of the commercial rights, and to a lesser extent the United States of America have shared in making the material and process an every day proposition. In Britain, utilisation of the unequalled merits of nitrogen-hardening was rather later, but British enterprise has shown itself in certain further developments to which reference will be made. Finality has not, of course, yet been reached, but the success which has already attended a wide variety of applications demand very serious consideration and interest in any engineering centre.

Nitralloy Steel.

As already indicated, the desired extreme surface hardness, together with strength in the core, was obtained by using steel of a particular composition. If a carbon steel or ordinary alloy steel be heated in the atmosphere of ammonia, there is some hardening

effect, but owing to the uncontrolled penetration of the nitrogen, the material is rendered so brittle that the hardening is of no value.

Very extensive experiments established that nitrogen possesses an affinity for certain elements, forming nitrides of these elements, and that for stability and intensity of hardness, aluminium is the most favourable. Others are, in the order named, molybdenum, manganese, chromium, vanadium, titanium, and tungsten.

The next stage was the development of a series of steels, really chromium aluminium alloy steels, which have been designated nitralloy steel. The four principal grades cover a range of carbon content of from 0.6 per cent. down to about 0.2 per cent., providing a range of mechanical properties which meet practically all requirements. The grades are known as Nos. 1, 3, 5, and 7 corresponding to the French designations LK1, LK3, LK5, and LK7, respectively.

Over the range of grades, the analyses do not show much variation in respect of the other constituents, chromium, aluminium, manganese, silicon, and small amounts of molybdenum, nickel, phosphorus, and sulphur. These are present in the following proportions, according to British makers' published figures:

Chromium	1.4 to 1.8	per cent.
Aluminium	0.9 to 1.3	,,
Manganese	0.65	,,
Silicon	0.35	,,
Molybdenum	0.9 to 0.25	,,
Nickel	0.25	,,
Phosphorus	0.02	,,
Sulphur	0.02	,,

The variation in the carbon content of the nitralloy steels makes available a considerable range of tensile strength in the core, this property having, it should be noted, to be imparted by suitable heat treatment; between the limits of carbon content named, however, the efficiency of the nitrogen-hardening is in no way affected—any one of these grades will surface-harden equally well under the standard treatment. The core properties are tabulated in Fig. 1.

Physical Properties.

The properties of the nitralloy steels, which after nitrogen-hardening are fully retained in the core of the piece, are in general those of high tensile alloy steels and they are comparable with nickel chrome steel. The heat treatment given to bring out their high characteristics is usually carried out by the steel makers, and consists of an oil-hardening from 900 degrees C. followed by tempering, the temperature for which may be 650 degrees C. for highest tensile strength, to 750 degrees C. for the lower limit of strength for the grade.

It is not recommended to heat-treat the grades to their top limits of tensile-strength, as there is a tendency for the hardening temperature to have a slight tempering effect on the core properties.

NITRALLOY STEELS

MECHANICAL PROPERTIES, TAKEN ON ·564" DIA. TEST PIECES MACHINED FROM 1⅛" DIA. TREATED BAR.

GRADE	OIL HARDENED FROM	TEMPERED FROM °C	TEMPERED FROM °F	MAX. STRESS TONS/SQ. IN.	ELONGN. %	YIELD STRESS TONS/SQ. IN.	IMPACT VALUE FOOT-LBS.
3 C·0·45%	900 °C (1652 °F)	650	1202	77·4	13·5	69·7	38
		700	1292	65·2	18	55·6	58
		750	1382	57·0	21	46·4	71
5 C·0·35%	DO.	650	1202	56·8	18·5	44	57
		700	1292	50·6	22·5	38	69
		750	1382	45·2	24	34·8	80
7 C·0·26%	DO.	600	1202	48·8	22·5	32·8	73
		650	1292	46·2	24	34	75
		700	1382	41·0	18	31	80

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THE SURFACE HARDNESS AFTER NITRIDING IS THE SAME FOR ALL GRADES.

Fig. 1.
Properties of usual grades of Nitralloy Steel.

The practice therefore is to utilise the four grades within the following limits of tensile stress :

Grade 1	... ...	70 to 90	tons per sq. inch.
„ 3	... ...	55 to 65	„ „ „
„ 5	... ...	40 to 55	„ „ „
„ 7	... ...	35 to 45	„ „ „

Machinability.

The nitralloy steels can be turned, milled, and drilled without any particular difficulty, using the slower cutting speeds usual with other alloy steels. Grade 1, having the greatest carbon content, should preferably be machined in the annealed state, and be oil-hardened and tempered thereafter. The other grades are quite machinable in the heat-treated state as supplied. There is a slight tendency for the material to drag in cutting, hence very light finishing cuts are advisable.

The user of nitralloy steel does not as a rule have to apply any heat treatment during fabrication of articles, if these are of fairly solid and symmetrical design, but in the case of parts having, say,

large area and small thickness like a clutch-plate, or large diameter in relation to wall thickness as in a cylinder liner, or considerable length like a pump spindle, or a retrousse shape like a crankshaft, it is necessary to anneal the article previous to final machining. This annealing treatment should be given at 500 to 550 degrees C. for four to six hours, followed by slow regular cooling. Given that all internal stresses are thus relieved before nitrogen-hardening, the hardened article is quite free from distortion.

The machining programme should also take account of any requirement there may be for keeping soft any portions of the article. Such portions have to be protected from the action of nitrogen, and this can be done by tinning the portions concerned. If the portion to be kept soft is at one extremity, the article can be machined outright and then dipped in the tinning bath to the required depth. On the other hand it may be desired to protect some intermediate portion : the procedure in such a case is to finish machine only the portion to be protected and leave about $\frac{1}{16}$ inch on the surfaces to be hardened, then the article is tinned all over, and the portions to be hardened are thereafter given their finish-machining.

Nitrogen-Hardening—" Nitrarding."

The hardening process consists of exposing finish-machined parts, made of nitralloy steel, to the action of ammonia gas in an electric furnace at a temperature of 500 degrees Centigrade or 932 degrees Fahrenheit, for a length of time up to ninety hours, according to the depth of case desired. The atmosphere of ammonia is thereafter maintained in the container until the contents have cooled down to 150 degrees Centigrade, after which it may be opened and the articles lifted out when cool enough to handle.

Articles so treated can be relied upon to possess a surface hardness greatly in excess of that obtainable by any other means in commercial use. The case hardness is so intense that the resulting surface is variously spoken of as being glass-hard and diamond-hard. Such superlative descriptions are justified by the ability of the nitrogen-hardened case to cut glass, and by the fact that it regularly tests between 1,020 and 1,170 by the diamond indentation method, as compared with about 740 for case-hardened chrome-vanadium steel, and 675 for high-speed tool steel. It is, by a considerable margin, the hardest surface known to present-day metallurgy.

That result is, moreover, obtained without any further treatment after removing the articles from the furnace ; they can be put into service forthwith, excepting only where an extreme degree of dimensional precision is demanded.

The process has been named the " Nitrard " Patent Process, and this is regarded as the registered name of the process. Applying the process can thus be spoken of as " Nitrarding," but for everyday

usage the term "Nitriding" is now being favoured. It is interesting to notice how many different appelations are to be found in the literature on the subject; besides those mentioned, there occur the following: "Nitration" (Britain and U.S.A.); "Nitridation" (France, Japan); "Nitruration" (France); "Nitrogenizing; "Nitrogenation" (France, Japan); "Nitrogenization" (Germany); "Nitrogen fixation"; and "Nitrification" (U.S.A.).

Nitriding Equipment.

The equipment required for carrying out the process consists of:

A tinning-bath for protecting in the manner described above any parts which are to be left unhardened. An ordinary solder containing lead and tin in the proportions 80 : 20 is the most effective, and the use of a liquid flux such as zinc-killed hydrochloric acid is helpful. It is important to remove all grease and rust before tinning, to immerse the portions concerned long enough to reach the temperature of the bath, and to remove all adhering excess solder that might drip off in the furnace. An alternative method, that of painting on a mixture of aluminium or chromium powder and sodium silicate also gives very good protection.

A degreasing bath, or a petrol bath followed by washing with hot water and drying with clean cloths, is essential for removing all traces of grease and fingermarks to ensure uniform hardening.

The electric furnace may be of any suitable design having reasonably close temperature control; in most installations automatic regulation of the current supply is employed, although not absolutely essential.

The furnace container is made of special material which resists the effects both of the furnace temperature and the ammonia-gas, and is fitted with a gas-tight cover and gas inlet and outlet tubes, also a pyrometer tube. The style of furnace usually employed has the container of rectangular box shape which can be withdrawn on runways; such furnaces have to be carefully sealed up at the front after the box is run into place. The licensed Glasgow Nitriding Centre employs furnaces of cylindrical design, of which Fig. 2 gives a general view. There are three sizes of furnaces in this installation having a nominal box capacity of ½ cwt., 1½ cwts., and 12 cwts., respectively. These furnaces were designed and made at the works of the local licensees, and have consistently produced very good work with no regulation other than hand-control. The permissible temperature variation is five degrees above or below 500 degrees C.

The Ammonia supply commercial anhydrous ammonia which is marketed in steel bottles containing about 56 lbs. weight.

A necessary item for proper control of the process is the gas tester in the outlet tube-line. At the temperature in the furnace, the ammonia is to some extent dissociated into its two constituent gases,

nitrogen and hydrogen, the latter having no effect under the prevailing conditions. Experience shows the optimum extent of dissociation to be 30 per cent., and this percentage is affected by the

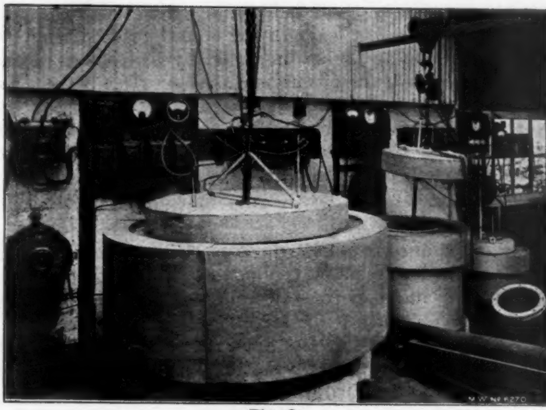

Fig. 2.
Electric Furnaces at Glasgow Nitriding Centre.

rate of gas flow as well as by the temperature, therefore it is important to have means for testing. Advantage is taken of the readiness with which ammonia dissolves in water. The exit gases are diverted through a modified form of pipette, and after ensuring that all air is expelled, the gas is bypassed and water is admitted from a small reservoir above the pipette.

The water, in dissolving the ammonia, fills the volume hitherto occupied by the undissociated gas, leaving unfilled the volume occupied by the dissociated gas. From graduations on the pipette the percentage can be read directly. The exit gas tube is not open to atmosphere, but dips into a water seal which puts a back pressure of half to one inch of water on the gas in the furnace system. A final exit tube can be led outside the building.

Case Characteristics.

The nitrided case is characterised not only by its unequalled hardness, but also by other interesting and important features. One, which is observable as soon as the parts are removed from the furnace, is the colour of the surfaces. On properly nitrided specimens, the colour is a matt, whitish, uniform grey, although on heavy masses it is quite common to find blue, purple, and pink areas of fantastic stream-lined shapes. Why such exotic colouring should occur has not yet been explained ; at any rate they do not indicate

anything amiss in the hardening. The colour is confined to an extremely thin film which is easily removed by touching up with fine emery. There is, however, a dull slate-blue colour spoken of by certain other nitriders which is stated to be due to either too high a nitriding temperature, or air being allowed to enter the container before sufficiently cool, or leaks in the container or piping. Colour of this nature is said to be accompanied by brittleness of the case.

The paramount feature of the surface is, of course, its extreme hardness, as already indicated, in comparison with other so-called hard materials. It should be emphasised, however, that this surpassing degree of hardness is quite regularly and dependably obtained in the commercial operation of the process, so long as the proper technique of heat treatment, machining, protection, and cleansing is carried out.

Of equal importance to the hardness at the surface is the variation of hardness with depth below the surface. Typical measurements for nitralloy steel nitrided the full ninety hours show the first .002 inch depth at the surface to be slightly below the maximum hardness ; in some instances this is lapped off before putting parts into service. The really important feature, however, is the gradual change from maximum hardness to that of the core, showing how the superhard exterior merges into the strong tough interior. This is in marked contrast to the more abrupt change between a carburised case and its core, with its vastly greater risk of the case being peeled or flaked off under severe wearing conditions.

The depth of the nitrided case, measured to the point where the core hardness is reached, is .030 inch, this being the result got by nitriding for ninety hours, and any longer treatment produces very little increase of penetration. Shorter treatment produces a case, not of lower hardness, but simply of less depth, the variation being roughly as follows : eighty hours, .028 inch ; sixty hours, .025 inch ; forty hours, .018 inch ; twenty hours, .008 inch. The treatment can thus be varied to suit parts having thin section which might be embrittled by being hardened to the full depth on both sides.

The nitrided case is therefore in general considerably shallower than the ordinary carburised case. Under the conditions for carburising already outlined, the depth of case would be .080 inch to .090 inch, that is, about three times the depth given by nitrogen-hardening.

The nitrided case has the valuable property of retaining its hardness in a great measure under hot working conditions, and of recovering much of its original hardness on returning to normal temperature. A nitrided case testing 1,100 Brinell hardness when cold, if maintained at 500 degrees C. will still have a hardness around 800 and will reharden to 1,100 on cooling down ; on the other hand a water quenched 1.2 per cent. carbon steel, initially 850 Brinell

hardness, heated to the same extent will soften to about 300 and would recover nothing like its original hardness. If the temperature is elevated further to 600 degrees C., the nitrided surface retains a hardness of 600 Brinell and on cooling regains nearly its original hardness; this restoration reaches about 950 Brinell. Even after heating to 800 degrees C. for one hour, and cooling to ordinary temperatures, the surface will have a hardness over 600 Brinell.

The high hardness values associated with nitrided nitralloy steel call for the use of hardness testing apparatus capable of dealing with such high range accurately. Above 500 Brinell or thereby, the ordinary Brinell equipment is not reliable. The figures quoted were determined largely by the Firth Hardometer employing a diamond pyramid indenter with a load of 30 kg. for cases of full depth and 10 kg. for the shallower cases resulting from shorter nitriding periods. Accurate determinations are also given by the Herbert pendulum machine fitted with a one mm. diamond ball. The Shore scleroscope, which measures the rebound of a steel ball-pointed weight falling by gravity from a fixed height, gives readings of 90 to 113 on the Shore scale, but with this instrument the reading is affected by the mass of the specimen.

Growth of Nitrided Articles.

As might be expected from the addition of nitrogen into the constituents of the surface material, slight increase of dimensions takes place during the process. This is, however, of a very small order; it is uniform on uniform sections; it is of the same magnitude on similar articles nitrided the same length of time although the articles differ considerably in size. Two round bars, of diameters one inch and six inches, nitrided together for eighty hours, would grow equally, increasing in diameter $1\frac{1}{4}$ to $1\frac{1}{2}$ thousandths of an inch. Another one inch diameter bar bored half inch diameter to form a thick-walled cylinder would grow the same amount outside, and the bore would be reduced by .001 inch. If, however, a third one inch diameter bar be bored $\frac{7}{8}$ inch internal diameter leaving walls 1/16 inch thick, the wall would expand .005 inch outside and .0012 inch inside. There is evidently a circumferential increase which with decreasing wall thickness more than offsets the reduction of bore; also, the increase of outside diameter occurs more freely as the core thickness and hence its rigidity is reduced. Allowances in the machining of relatively thin cylinders are best determined by completing a trial cylinder.

On average more or less solid shapes, the growth is of the small magnitude mentioned for the solid bars, and excepting only very high-class precision work, the parts are put straight into service, sometimes without even buffing off the coloured film.

Distortion.

The phenomenon of growth is bound up with that of distortion, which may occur in unsymmetrical shapes, or parts unsymmetrically protected, due to unequal areas being exposed to the hardening gas and causing differential growth. A shaft, for example, having a single long keyway would tend to bow into a curve with the keyway on the outer side of the arc, due to the greater exposed area on that side ; if, on the other hand, the keyway is protected, the tendency would be in the opposite direction, because there would be no hardening and thus no growth longitudinally on the keyway side. Thin cylinders nitrided both inside and outside, do not distort at all, but if protected on the outside, there is a tendency to bell-mouth at the ends, but not so much as to require the removal of an undue amount of the case to correct them. On large diameter cylinders this tendency is checked by leaving a collar at the ends to be machined off later.

Apart from these extreme instances, distortion in the sense of change of shape is entirely absent, as the treatment temperature is considerably below the critical temperature of the material, and the treatment is not followed by quenching, consequently there is no tendency for deforming stresses nor quenching cracks to be set up as in carbon case-hardening.

Variations in Composition and Conditions.

A good deal of experimental work has been done in this country and abroad on the effects of alterations in the analyses of the steels and in the gas composition, gas pressure, and furnace temperature. In no instance has any better composition been found than that determined by Fry, beyond the variation of carbon content to give a range of available tensile strengths, the hardening being unaffected over the carbon range of the standard grades. The same is true of the standard conditions of treatment in the furnace—even considerable additions of hydrogen, or of coal gas, or of carbon monoxide to the ammonia do not have much deleterious effect. Higher temperature, although it increases the penetration, results in reduced surface hardness. Higher gas pressure accelerates the hardening slightly, but does not increase its intensity, although the depth is increased and the hardness gradient from surface to core is further reduced.

Wear and Fatigue Resistance.

The superior durability of the nitrided case has been well demonstrated by investigators in Europe and the United States. Tests of wearing quality carried out on an Amsler machine with loads up to 80 kg. (176 lbs.) showed that all of a series of four case hardened alloy steels suffered losses of weight exceeding two centigrams

each, whereas the nitrided nitralloy steel showed no measurable loss. Even when the loading was increased to 200 kg., the loss of weight of the nitralloy specimen amounted to only 0.26 centigram. Such comparisons are borne out in actual service, as for example a four months' test between 1.5 per cent. silicon steel and nitrided nitralloy steel dredger pins 1.7/64 inch diameter under identical conditions in river sand dredging, which resulted in the former being reduced in diameter 19/64 inch and the nitrided pins only 1/64 inch, and again in service tests of automobile cylinder liners extending to 30,000 miles of running, nitralloy steel showed no wear, as against an ovality of 0.016 inch in cast iron. The nitrided liners prolonged the life not only of the cylinders, but also of the pistons and rings which likewise showed no wear. Similar good results are being obtained by the use of nitrided special cast iron liners. (See "Nitricastiron" below).

The wear resistance is further demonstrated also by the example drawn from local experience shown on Fig. 3, which illustrates the

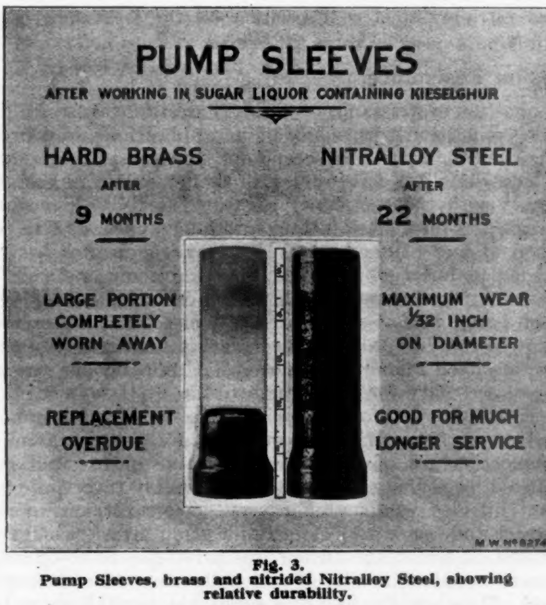

Fig. 3.
Pump Sleeves, brass and nitrided Nitralloy Steel, showing relative durability.

condition of centrifugal pump sleeves after working in sugar liquor containing filter-aid of an abrasive nature. The serviceable con-

dition of the nitrided sleeve after twenty-two months' work contrasts very strongly with the brass specimen, of which a large portion has been completely worn away in nine months.

As regards resistance to fatigue in parts working at high speeds and under alternating stresses, nitriding raises the fatigue strength to a remarkable degree, attributed to the tremendous increase in the strength of nitrided case, due to its exceedingly dense structure preventing the starting of fatigue cracks. An investigation undertaken in the United States on nitrided against unnitrided specimens, under an alternating stress of $33\frac{1}{2}$ tons per square inch, showed that nitriding increased the endurance 66 times; the unhardened piece failed after 40,800 reversals of stress, whereas the nitrided bar lasted out 28 million reversals. Another interesting trial on automobile crankshafts, is also worthy of mention. One maker of high-class cars tested nitralloy shafts against standard shafts by locating a centre bearing .040 inch out of line with the end bearings, and running the shafts to destruction at a fixed speed. Under these conditions, standard shafts broke down after about 75 hours; nitrided nitralloy steel shafts withstood the treatment for about 1,500 hours.

Corrosion Resistance.

The question of resistance of nitralloy steel to corrosive influences arises in connection with many of its applications, and in certain instances has an importance second only to its resistance to abrasive wear. Accordingly, a brief review of the behaviour of the material in contact with the commoner corrosive media is here desirable.

As regards atmospheric attack, nothing appears to have been published of any planned test. However, the author has a piece of nitrided material which has been lying about more or less in open air for three months—the surface shows no marking; the specimen is one half of a fractured test-piece, and the unhardened core showed rust like ordinary steel, but it is noteworthy that the case section itself remains quite clean. A much longer exposure is, of course, necessary for a thorough test.

The corrosive effect of waters is a matter of great importance in nearly every industrial undertaking. Published statements in this connection are of a purely qualitative nature and may be summarised by saying that unnitrided nitralloy rusts quite readily, but that nitrided samples offer very good resistance to running fresh water and sea water. As a result of an investigation recently undertaken, in which the author was privileged to co-operate in a small measure, some results of rationally planned tests have been obtained. These are the first of a series which will have to be continued for a considerable further period before they can be regarded as conclusive. They cover, to date, tests with tap water, salt water,

and weak soda ash solution and, very briefly stated, they indicate the following, taking as a basis the rate of attack on common cast iron :

In Tap Water	Mild steel ...	150	per cent.
	Nitricastiron ...	20	,,
	Nitralloy steel ...	zero	
In 20 per cent. Salt Solution.	Mild steel ...	45	,,
	Nitricastiron ...	80	,,
	Nitralloy steel ...	25	,,
In Weak Soda Ash	Mild steel ...	130	,,
	Nitricastiron ...	85	,,
	Nitralloy steel ...	9	,,

Another test, in a salt water spray using 20 per cent. salt in water, after one thousand hours, mild steel and nitricastiron each showed a rate of loss expressible by the figure 412 in comparison with 14 for nitralloy steel.

A test in tap water using an electrical Corrosimeter yielded further interesting relative figures for rates of loss. Mild steel 610, Staybrite 15, stainless steel 20, nitralloy steel 32. The results so far obtained, therefore, do point to the possession of corrosion resisting property to a marked degree, and one looks forward hopefully to a paper embodying the final results at the proper time and from the proper pen.

Nitrided steel has found very important uses in valves and other fittings for superheated steam, due to its high corrosion resistance in that medium, together with great hardness and retention of hardness at high temperatures—a combination of properties which should commend the material to steam engineers. A like appeal cannot, however, be made to chemical engineers, as the resistance to acid attack is rather low. On the other hand, caustic soda is well resisted except where the strength is over 50 per cent. and the temperature is near the boiling point.

It may be that the resistance which nitrided steel does possess is due more to the impenetrability of the surface than to the composition. In any case, much work remains to be done on this aspect of its capabilities before it can be given its correct orientation among resistant materials. Where the working conditions include the commoner corrosive media like ordinary atmosphere, water, and sea water, there is every reason to expect a high degree of durability, where the duty demands both high hardness and corrosion resistance.

A large field of investigation also lies in the effects of corrosive agents formed by and under the working conditions. To mention one only, the part played by corrosion in the wear of internal combustion cylinders has been having close study by the research depart-

ment of the Institution of Automobile Engineers who state, in a recent interim report, that in their opinion, cylinder wear is in the main a matter of corrosion, not erosion. Evidently hardness alone

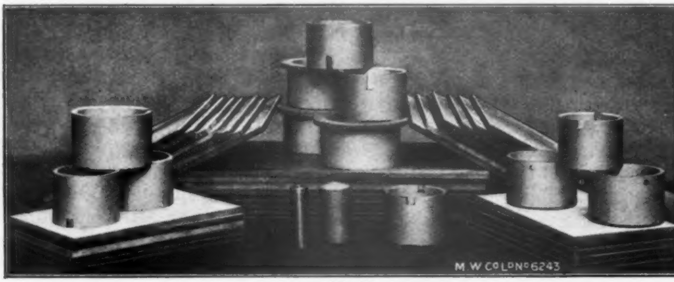

Fig. 4.
Nitrided Bushes and Plates.

is not enough and, given two materials of equal hardness, the one possessing higher corrosion resistance will, according to this finding, have the longer life.

Applications.

In the comparatively short history of the material and process since its introduction in this country, nitrided nitralloy steel has met with outstanding success in a great many applications in industry. So many and varied are its present-day uses, that full enumeration of them, if accompanied by particulars of the extent of the advantages gained, would provide ample material for another paper. The exceptional characteristics already described, giving rise to its high wear resistance, offer a means to greater ends, namely, the reduction of maintenance charges together with increased output due to plant functioning more efficiently and for much longer periods, greatly reducing the time machinery is out of service. These are the constant aim of all users of machinery, and, in this age of service, ought to be embodied in the wares of all producers of machinery.

The industrial applications are already well listed in steelmakers' catalogues, technical press articles, and papers read by those responsible for the introduction and development of the material in this country. The uses mentioned here are therefore confined to examples taken from experience in the Scottish area, with which, therefore, the author has had some personal contact.

Class of Machinery.	*Applications of Nitralloy Steel.*
Air compressors and the like ...	Valves, seats, cylinder liners.
Conveyors and elevators ...	Bushes and sleeves.
Centrifugal pumps	Shafts ; shaft sleeves (see Fig. 3)

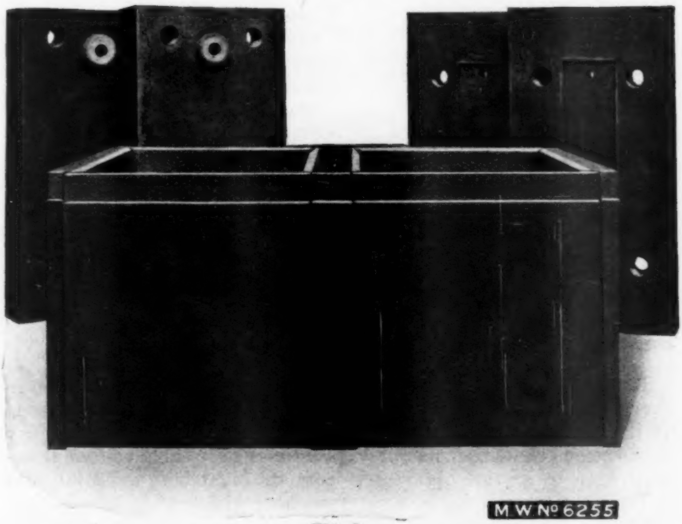

Fig. 5.
Nitrided Brick Press Box Liners, with forged steel Stamp Blocks.

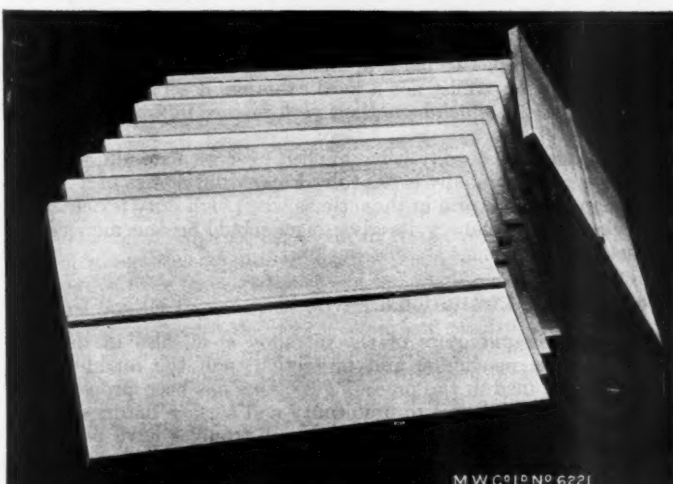

Fig. 6.
Brick Press Liners, nitrided. (Part of larger consignment).

Textile machinery	Thread and yarn guides, pinions, bevel wheels.
Loco valve gear	Caprotti gear parts.
Pneumatic tools	Governor parts, valves, valve seats.
Wire-weaving machinery ...	Stepped cones ; drawing rolls.
Grinding and woodworking ...	Shafts and spindles.
Motor vehicles	Shackle pins ; liners for brake drums.
I.C. marine engines	Cylinder liners ; governor pump wheels and other parts.
Paperworking machinery ...	Back rolls for paper cutting machines.
Die stamping machinery ...	Die blocks.
Brickmaking machinery ...	Press box liners.

The last named application, of which illustrations are given in Figs. 5 and 6, is of interest by way of indicating the benefits offered by the combination of surface hardness and core strength. Lengthy observations show that nitralloy steel liners give three to four times the length of service obtainable from the next best material, and produce a correspondingly greater number of bricks of satisfactory accuracy. The accuracy of slab dimension is particularly important in modern firebrick making, thus the relative absence of wear means that nitralloy liners make more first-grade bricks, and that the formation of fringes along the edges of the clay slab is largely eliminated.

Some applications to parts in Diesel engines for land service are shown in Fig. 7 : whilst not a local example, it serves to show the variety of articles which have their performance improved by use of nitralloy steel.

The material is steadily being applied over an extending field of usefulness ; undoubtedly it has solved many difficulties of designers and operators alike, and in these times when high duty is demanded of all classes of machinery, its advantages should become increasingly important.

Troubles and Limitations.

If, in the manufacture of the nitralloy steel, also in the heat treatment, the machining and protection, and the nitriding, the technique outlined in the preceding sections has been properly carried out, the high claims to uniformity and surface hardness of the product are consistently fulfilled. Where troubles have been met, they have generally been traceable to a particular cause, or to applications for which the best advocates of the material would not specify it.

In a few isolated instances, local softness and flaking of the nitrided case have been encountered. Such faults can arise: (*a*) If, in the heat treatment, the tempering temperature has been

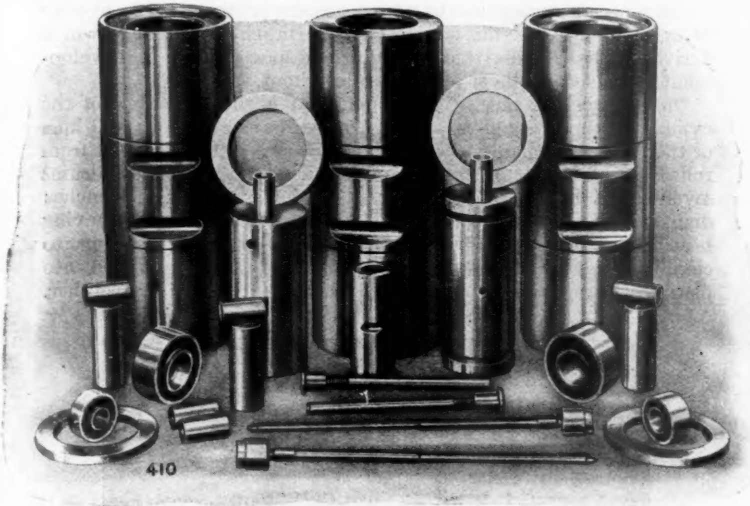

Fig. 7.
Some Mirrlees-Diesel Engine parts in nitrided Nitralloy Steel.

pushed too high. (*b*) If, in the machining, sufficient material has not been removed from the surface as forged or rolled, with the result that the surface has not been entirely free from scale, decarburised surface material, or traces of the protective tinning. (*c*) If, in the tinning, the excess solder has not been thoroughly wiped off, allowing of drips falling when in the nitriding box. (*d*) If, in the nitriding, the conditions are not maintained constant and in accordance with those outlined earlier; or if air has been allowed into the box, or the box has been packed too full, or the cover has been removed before the contents are sufficiently cool.

These eventualities may sound formidable, but in reality the procedure is simple and straightforward; such occurrences are not at all difficult to avoid, and rarely arise. Fringing of the case at sharp corners and edges is easily avoided by putting a small radius on such portions. As regards unsuitable applications, these are confined to such conditions as knife-edge contact under heavy loading, severe localised impact, fierce heating and cooling, severe bending stresses, and certain uses, like sand-blast nozzles, which

demand hardness of much greater depth than that of the nitrided case.

Nitrided Brake Drum Liners.

One special application in motor vehicle construction is worthy of special notice. This is the Laystall brake drum liner, which derives its name from that of the firm responsible for its development, and is the subject of a separate patent.

On the working face of the drum, that is the inner face of the cylindrical rim, a shallow recess is turned, having a width half inch or thereby larger than that of the brake shoes. The liner is cut from rolled nitralloy steel strip, one mm. thick for the smallest drums seven inches diameter, to $\frac{1}{8}$ inch thick for the largest drums 24 inches diameter, the required exact length for a neatly butting joint having been pre-determined from a formula. The cut strip is bent to circular shape by means of bending rolls and the liner slipped into place in the manner shown in Fig. 8, the ends just butting together.

Fig. 8.
Fitting Laystall Liner into skimmed Brake Drum.

The liner is then nitrided in place the drum itself being protected in the region of studholes. After nitriding, the face of the liner is given a light grinding to remove the surface film and ensure smoothness. Fig. 9 shows a short type of lathe suitable for turning the recess, with the grinding head being brought forward for finishing a hardened liner. This lining process makes use not only of the hardening effect of nitriding, but also turns to useful account the

linear growth of the nitralloy strip under the treatment. The elongation swells the liner outwards into the recess, and as the growth is permanent, as distinct from ordinary thermal expansion and

Fig. 9.
Grinding Laystall Brake Drum Liner after nitriding.

contraction, the liner without any special means of fixing thus securely binds itself in position.

The Laystall liner has made great headway in the reconditioning of worn drums, and is found to resist scoring over very much greater mileages than the whole life of new unlined drums under the severest operating conditions. Moreover, the braking effect is much smoother and stronger, it is consistent throughout large mileages, and there is definite reduction of snatching or jerking in the brake action and of the risk of the vehicle skidding. Drums with this lining have been on view at the recent exhibition at Olympia which show excellent unscored braking surface after 120,000 miles in service. Arrangements were recently made for re-lining worn brake drums in this way at the local nitriding centre. While it is too soon to give first-hand results as regards mileages, it can be testified that the claims in regard to improvement of braking effect are fully met.

Nitricastiron.

Reference has been made in a preceding section to nitricastiron, and it will be fitting to describe briefly what this is. Nitricastiron is an aluminium-chromium cast iron suitable for surface-hardening by the " Nitrard " process. Both in the centrifugally cast and sand cast forms it has higher moduli of elasticity and rupture than

ordinary centrifugally-cast material. As nitricastiron possesses some air-hardening property, castings are annealed and slowly cooled before machining; later, between rough and finish-machining, the castings are preferably hardened and tempered in order to get the best result from the nitrogen-hardening.

The surface of nitrided nitricastiron has very nearly as great hardness value as nitralloy steel, and rather less penetration. Figures published by J. E. Hurst include the following as a typical comparison:

	Firth diamond hardness	Depth of penetration Inches
Centrifugally cast nitricastiron ...	962—982	.016—.018
Sand cast nitricastiron	894—904	.015
Nitralloy steel, grade 3	1,066	.026

Specimens were all nitrided together for ninety hours.

Nitricastiron and its applications have already been discussed in various publications, but it may be here mentioned that it is proving of considerable advantage for centrifugally-cast cylinder liners for internal combustion engines, and some parts for which the steel is not available in the most economical form as, to take a local example, a hollow backing roller for mounting on an existing cutter shaft of a paper cutting machine. Nitralloy steel tubing of the required diameter, five inches, was not available; machining from solid bar was ruled out on cost. Nitricastiron tube, centrifugally cast, was utilised instead and nitrided in the usual manner with excellent results as regards surface hardness, freedom from distortion, and ease with which it took a high surface polish. In such ways as this, nitricastiron and nitralloy steel should develop side by side in extending their usefulness.

Conclusion.

To sum up, in nitralloy steel and the nitriding process, there is made available an important metallurgical advance which enables designers to make further headway in meeting and countering the severe wearing conditions that arise in many classes of machinery, and the indications are that this material is also of considerable value for resisting corrosive influences. The main features of nitrided nitralloy steel, namely, unequalled surface hardness, core strength, and undoubted corrosion resistance, surely form a trinity of properties which put it in a position of unique importance among the materials of engineering construction.

Discussion.

MR. R. J. TAYLOR: I am interested from the point of view of corrosion of nitralloy articles. The author mentioned that these articles had been used for superheated steam valves. I take it he referred to seats, discs, heads, lids, or spindles. One of the great difficulties in components for steam manufacture is where one part is pressed into another part and that other part is not of the same alloy or construction as the component which is pressed in. I can imagine a situation such as a nitralloy seat being pressed into a steel casting. I would ask if he has any experience of what happens if the seat was pressed into, say, a cast steel valve casing (the valve working in superheat at 840 degrees C.) and the plant was shut down suddenly and allowed to cool? Does he think the seat would cool quicker than the body and that a shrinkage would take place and it would become loose?

MR. MCCRONE: With regard to this particular application of valve seat being pressed into a cast steel body, that is an application of which I have no first-hand experience. It is known, however, that nitralloy steel is very close to ordinary steels as regards coefficient of expansion, and basing on that fact, I would not anticipate a loosening effect on cooling down from a high temperature.

MR. W. BUCHANAN: One point is the long time necessary for the process. This necessitates in many cases the alteration of the production programmes to accommodate the nitriding. Is there any way in getting the time reduced?

The author never touched upon the question of cost. How does it compare with case hardening? We got very poor results with nitralloy plugs for drawing tubes. These plugs loaded up very much more quickly than 1.2 carbon and chromium plated plugs.

Also, a nitralloy spindle which was working in 430 degrees F. feed water pitted up very badly. I would ask him if there is any data available for the rubbing of nitralloy rods in nitralloy tubes under moderate pressures of 200 to 500 lbs. per sq. in.? Also, if he has any data on the effects of milk or other products like the food line? How do they affect nitralloy?

MR. MCCRONE: The time taken to carry out the process could be reduced if it would be sufficient to have a shallower depth of penetration. Owing to the action of the ammonia on the alloy, the time I mentioned—up to ninety hours—is essential for that action to take place thoroughly. Various expedients have been tried with a view to accelerating the action by altering the conditions of, for instance, temperature, gas flow, and gas pressure, but where any acceleration was produced there was no advantage in

doing so because it was found that the resultant surface hardening was not up to that obtained under the conditions I have outlined. Regarding the cost of the nitriding process as compared with case-hardening, I should say that, by the time you have considered not only the cost of the carburising operation itself but of the re-heating and second re-heating required, and the liability there is in carburising for a considerable percentage of spoiled work, after all that has been taken into account together with the extra life in service, that the cost in the long run will not be to the disadvantage of nitriding. Plugs for drawing tubes: This trouble is a new one to me and I do not think there is much I can say about it at the moment without actually seeing the plugs themselves. Spindles working in high temperature feed water: This indicates a line along which further research into corrosion resistance is desirable. This is also a type of trouble I have not actually been up against. Nitralloy rods working in nitralloy tubes are analogous to nitralloy rams in nitralloy barrels and trials on such applications have shown they work very well and that there is no undue friction as compared with other materials. The effect of food products: The effects in special applications such as these would depend upon the acidity or non-acidity of the material, and as far as milk is concerned it would depend upon the age of the milk. I indicated in the paper that the resistance to corrosion was not "good," and I think from that point of view nitralloy steel would have to be very carefully tried before being adopted.

MR. PLATT: Is there anything at all against the gas furnace or even solid fuel? How do sharp corners such as the sharp end of a plug gauge or reamer behave on nitriding? What would you expect from a very sharp reamer? In all the cases he spoke of depth of case as 15/1000ths. Now, on small work you require one to 5/1000ths depth of case. Would you get a hard case to give a depth of 1/1000th or would it be soft? Regarding the growth of material nitrided, would the actual measurement of growth on a uniform section be an absolete indication that it had been correctly nitrided? Would it give any indication of the nitrided case? Is there a hardness of nitrided steel always constant at the surface irrespective of the depth of case. If you have only 2/1000ths will the surface hardness be just as hard as if you had 10/1000ths?

Regarding the rustless properties of nitriding, what class of polish would a nitrided surface take? Will it polish up like Staybrite, or would it have a colour which could distinguish it and be objectionable? Can the nitriding process be stopped after a short time and then continued, or a part taken out of a box when the process had gone a certain length of time and the remainder then put back again to finish off. Would he agree that, say, for a small turned bar weighing about half-lb. it would cost about four times that of three per cent. nickel case-hardening?

MR. McCRONE : I have not heard of gas or solid fuel being operated in connection with nitriding. It is one of the conditions that the heating should be quite regular and uniform, and from that point of view there is possible objection to the use of solid fuel. As regards gas fuel I think it would not be advisable to introduce other gases near or in the region of the nitrided parts just in case there was some mechanical difficulty giving rise to leakage. Where sharp edges are unavoidable the slight fringing effect I spoke of is objectionable or not according to whether the part is a working part or not. At the edge of a plug gauge it may not be on the important working portion of the gauge and then it would not matter. But on reamers where you have the edge having to do work on other metal I should imagine, in such a case, it would be rather objectionable. The hardness of very thin cases is up to the hardness of the full case, fifteen hours or so giving about eight to 10/1000ths depth. Below that I cannot say. For 1/1000ths depth of case, I do not know of that ever having been tested. Growth as a measure of correctness of nitriding would have to be worked out for some standard length of test piece or some standard item of work. It would also have to take into account the grade of nitralloy steel in use. It is possible for a given grade and a given initial length it might be taken as a rough guide to whether the standard nitriding had been carried out. Nitralloy steel will polish up to mirror polish and will not have any distinguishing colour. The process can only be stopped and a part removed if you stop the process as you would at the end of a full run. That is, allowing the gas to continue circulating through the box until parts are thoroughly cooled. It is not advisable to admit air when the parts are hot, and that would involve some loss of time considering the other parts which had to be brought up to the temperature again and the process continued. The process cannot be stopped and the box opened immediately, then the box closed and heat put on. There would be a gulp of air in the box which would have an harmful effect. Cost of very small part : It is quite possible for the cost of a small part to be greater than that of, say, a nickel chromium steel article. But, of course, a little part can cause a great deal of trouble if it does not have the serviceable life of a nitralloy steel part.

MR. S. M. HARDAKER : I noticed that the slides illustrated some pins showing differences in wearing action. Can he tell me what effect regarding wear a special lubricating oil would have ? This oil has a certain acid constituent which enables it to function particularly well. My experience of Firth Staybrite is that it was useless. He refers to elevators and conveyors. What part of the elevator was he referring to, was it bearing parts or the bucket runway ?

MR. McCRONE : I should imagine from want of first-hand experi-

ence of this special lubricant that the acid content of this oil would indicate some caution. I think it would be well worth trying nitralloy steel even though it did not show up any better than Staybrite. The pins shown on the slide were non-lubricated except for the river water in which they worked. The elevator parts were the pins and bushes connecting the links. Runways have not been tried, so far as I know, in nitralloy steel.

Mr. J. W. Mallett : With regard to the drum liner it was not clear to me whether it is a process from the beginning or a maintenance or repairing process. For instance, if special steel is required—special nitralloy steel—to prevent excessive penetration of the nitriding process, then I take it you cannot take brake drums from service because the nitriding process might have deleterious effects. Some six years ago the Standard Car Co. built an engine with a nitralloy crank shaft and they put it on the road with the crank shaft running direct into the cast iron. The idea was that the hard steel would stand up to the cast iron. Does the author know the final result of that experiment ? It seems to be one of the most far-reaching processes to which the steel can be applied. If you take the high speed light engines and could get a crank shaft hard enough then you could run aero engines with hard crank shafts and bronze bushes.

Mr. McCrone : The Laystall liner was introduced primarily for repair or maintenance jobs, and the liner is fitted into ordinary drums in everyday use. The drum itself is not tinned. For protection, silicon paint is used and it is quite serviceable for the purpose. In theory the whole drum, with the exception of the face of the liner, should be protected, but in practice I believe it is not done so thoroughly and the usual way is to protect only the centre portion around the stud holes where the drum itself is held to the wheel and where the greatest stresses come on. The Standard Co.'s experience with nitralloy steel crank shaft : I have not heard the final result of that particular experiment, but it will be of interest to mention that the French car, Citroen, has a nitralloy steel crank shaft as standard, working without bushes in aluminium alloy connecting rods. The soft rods and the hard shaft make an excellent working combination, and my information is they are standardising it.

Mr. M. McFarlane : Unfortunately the author has not given us very much information about the costs. I am thinking more about articles of somewhat complicated shape and where, according to Mr. McCrone it would be advisable to anneal and after that you have to oil, harden, temper, and then nitride, and that together with the length of the nitriding process seems to add very considerably to the cost. Take a simple part, plugs, would he compare the cost against chromium plated plugs ? Information of that character

even though it was only relative, I should be pleased to get from him In connection with gauge making we have to meet all sorts of conditions, and I have taken the liberty of bringing a few and I would like his opinion as to how he would treat some of them. Where there are a large number of holes you have to guard against cracks and distortion. Take an ordinary calliper. We only want surface casing and these would have to be treated in different consignments, and if you only have a small quantity is not that going to raise the cost ? Take a plug gauge which has also to be used as a hammer owing to special circumstances—if we can get a surface that is a good deal harder than we can get from case-hardening or chromium plating—if we can get a nitrided surface to resist the hammering as well as the gauging—we shall be pleased.

Mr. McCrone : Cost results compared with carbon case-hardening. I can only repeat what I have said before and add that the annealing which I mentioned for awkward shapes of parts does not have to be followed up with oil-hardening and tempered again except where you are using Grade 1 steel. For other grades supplied in the oil-tempered condition it is sometimes necessary after machining to stabilise the part. Where you have a small consignment of small parts, in the ordinary course of events, they would be nitrided along with other consignments and the whole cost of running the furnace for eighty hours would not be loaded on to these small things. As a commercial proposition it would not be desirable to have charges fluctuating according to the work in hand. The points raised by Mr. McFarlane regarding his assortment of gauges are interesting, but from the nature of them and their quantity I think they should form an inquiry through the ordinary business channels. The case shown in the broken one is about three times that of the nitrided case. Where he wants to regrind the surface showing a slight taper, the depth of wear round the gauge is only a fraction of the nitrided case and therefore can be trued up again without having to be re-nitrided. A large number of small parts for pneumatic tools have been nitrided locally and had to have a pin driven in later on, and by protecting the hole from the nitriding action the pins could be driven in without any trouble.

Mr. Geddes : I recall a job I got and I was disappointed when I was informed that nitralloy would not be suitable. I refer to beaters for a cinnamon pulverising machine. They were of square section fixed round a shaft revolving at 3,000 r.p.m. The specification called for a steel which was extremely hard on the surface and must not chip or flake off, and it had to have a tough core because if any one of these arms were to break it would practically ruin the machine. The arms which were fitted were not satisfactory. They were all right in sugar but in cinnamon they failed completely. I was disappointed because I had committed myself to this material. The

reason given was that there was no fear of the arms or beaters breaking off but through time the hard surface would probably break off. Has the author any experience of that class of work and would I be safe in offering such a material ?

Mr. McCrone : The application Mr. Geddes refers to is a very exceptional one, and I must say I have not actually experienced one like it. Actually a trial is about to be undertaken with a beater-head on a disintegrator—a much larger machine, but for a different purpose. The probable underlying idea for the objection being raised against nitralloy and the nitrided case (if I understand his description correctly) is that with a sharp square edge doing the work that is where the trouble would begin. If it were permissible to start off with a small radius there would be much less danger of chipping off the case.

Mr. Buchanan : Regarding case-hardening in which an oil rich in hydrocarbons is injected along with the gaseous ammonia, is that not a sort of nitiriding process ? It is faster than the method described by Mr. McCrone. The particular steel dealt with has a percentage of molybdenum. In many cases machines are constructed with shafts and bushes in very inaccessible positions. What is the author's experience of shaft and bush working together using nitralloy steel without any lubrication whatever ?

Mr. McCrone : This process which Mr. Buchanan has mentioned—injecting some oil, rich in hydrocarbons in conjunction with gaseous ammonia, is not a straight nitriding action. There may be a partial action, but the molybdenum has less affinity for nitrogen than the alloying elements in nitriding steel. As regards pins and bushes working together, both in nitralloy steel, I have come across them working together without lubrication. I have come across pump rams and barrels not lubricated, working with a considerable measure of success.

Mr. A. Craig Macdonald : With reference to ordinary carburising process, how does Mr. McCrone reconcile his advice that the carbon content of the case should not exceed 0.90 per cent. with his statement that 3/32nds of case depth is produced in five hours after attaining the carburising temperature ? Will such rapid penetration not cause the 0.90 per cent. carbon limit to be exceeded considerably ? In his reference to cyanide hardening, Mr. McCrone states that the fumes evolved are poisonous. That is surely not so. They are certainly irritating to the nose and throat but are not poisonous. In any case they are seldom in evidence if the surface of the cyanide is covered with a flux of, say, boric acid and graphite. Mr. McCrone mentions 675 as the diamond hardness of high speed steel in his comparison with nitrided jobs. Would it not be fairer to say that the better qualities of high speed steel will give a diamond hardness of 867 to 902 when properly treated (e.g., Stag Major) ?

The advantage which nitrided steels possess of increased fatigue resistance is, of course, shared by ordinary case-hardened steels in proportion to the greater tensile strength of the surface as indicated by the diamond hardness figure. One more point. How are nitrided steels thoroughly softened for remachining in cases of error? Can they be satisfactorily re-hardened in such circumstances?

Mr. McCrone: When speaking of ordinary carburising, I was not advising one way or the other; I was merely stating what I knew to be the usual result of carburising as carried out by certain people known to me. They carry out their case-hardening on steel of very low initial carbon content, which may account for the hardened cases on their work not exceeding 0.90 per cent. carbon. Mr. Macdonald does not think I have assigned a high enough diamond hardness value to high speed steel, which he states should be 860 to 900, whereas I gave it as around 675. No test on heat-treated Stag Major I have carried out has yielded any higher value than 750; such high values as Mr. Macdonald claims for Stag Major may result from special treatment. Nitrided nitralloy steel can be softened by various methods. One is by immersing in a bath of fused sodium potassium nitrate, which brings about a marked reduction of hardness. Another is by heating in aluminium powder to the melting point of aluminium, which fuses with the nitrided case, making it easily machinable. The case-hardness is restored by the usual nitriding treatment.

MOTION STUDY APPLIED TO ENGINEERING.

Abridged report of Paper presented to the Institution, Manchester and Coventry Sections, by A. G. Shaw.

INDUSTRIAL psychology is the science which considers the reactions of individuals in relation to their daily work. Motion study is that section of industrial psychology which aims at reducing the movements used in doing the work, and at eliminating all unnecessary fatigue.

Every science develops laws of action for the material it studies, but before this can be done, methods of measuring the reactions of this material have to be found. The same thing is true for the study of movement. Methods of measuring the movements have had to be found, and from these general principles of motion economy have been formulated.

Methods of Measuring.

Those methods used in motion study were devised and developed by Lilian M. and Frank B. Gilbreth in America.[1] They are three in number :

(1) Process charting gives the picture of a job as a whole.
(2) Micromotion photography measuring the nature and type of the movements.
(3) Chronocyclegraph study from which it is possible to analyse the path of the movement.

Process Charting.—The first method of approach in any investigation is that of process charting. Process charting may be defined as the graphic method of describing a process to obtain the basis for measuring and improving it. Here each detail of the operation is recorded in sequence by a symbol representing its characteristics. In this way a complete picture is given of the job, and the stages and departments through which it passes. The process is shown up in an entirely new light, and every deviation from the standard practice becomes obvious, while stages come to light which are not at all apparent in the work itself, or an ordinary written description of it.

Coventry, November 8th ; Manchester, November 13th, 1933.

[1]F. B. Gilbreth "Motion Study" New York, 1911.
F. B. & L. M Gilbreth "Applied Motion Study" New York, 1917.

The operation unit on a process chart can be so large that its charting covers the progress of the article right through the factory, or it may be reduced to describe the work in any particular department, or smaller still to show the details of a single operation, in which latter case the individual movements of the operator become the units of investigation. This is satisfactory so far as it goes, but it considers the job for its own sake, and does not give adequate attention to the operator. It is micromotion photography which emphasises the significance of the human element.

Micromotion Photography.—In this second method, interest is concentrated on the operator's actual movements. Motion pictures are taken of the operation under investigation with a clock, which gives a reading to .0005 of a minute, in the field of view. This film is then projected a single frame at a time, and the movements of all parts of the body involved in the work are analysed into basic elements of motion, or Therbligs, as the Gilbreths called them. The Therbligs used by various limbs, etc., are charted for every reading of the clock, and from this it is possible to discover the type and duration of movements, and the co-ordination between them.

This information may be adequate for some investigations, especially as this analysis, like that of the process chart, can be reduced to such detail as the individual movements of each joint of the fingers, in cases where such is required. Unfortunately, however, owing to a moving picture being a series of still pictures projected at a certain speed, it is not possible to measure the exact path of the movement, and as this is an important criterion of a cycle of movements, it may be necessary to use the third method of measuring.

Chronocyclegraph Study.—The chronocyclegraph is a dotted line graph on a stereoscopic photographic plate. It is obtained by taking a picture of the cycle of movement under investigation with lights attached to the hands of the operator, which flash intermittently at predetermined speeds. From this graph the speed, acceleration, retardation, and rhythm of the movements in three dimensions can be accurately measured.

Development of New Method.

The investigator, when beginning the study of an operation, considers the importance of the job and what expense is justified in setting up the new method. He usually finds that the job falls into one of three categories.

In the first category there are complex jobs, or those which are particularly important in the finished product or have a large production, or are similar to a number of other operations, so that any improvement made in them can be widely applied. For this

group it is usually worth while using all three methods and aiming at 100 per cent. efficiency. It has been found that such operations as coil winding, taping, detailed or complicated assembly work, and some types of repetitive machine work are in this group. In the second group, where operations are simpler or have a smaller production, the investigator may only need to use the process chart. While in the third group come the jobs where there are only one or two made at a time. Here he applies the general principles of motion economy, and tries to make the new method sufficiently elastic to be adaptable to several types of jobs. In this case, of course, he does not obtain nearly such a high percentage of efficiency, but as high as is consistent with the nature of the job.

If the investigator decides that the job warrants thorough investigation, he makes a process chart and from this he alters the flow of material, the sequence of operations, and the quality or accuracy of the material. When he has considered all possible alterations from this aspect he turns to the detailed movements of the operator, and very carefully analyses the micromotion film and chronocyclegraph. He may find that he has to modify his material improvements to bring them in line with the movement alterations. He combines all his results to obtain the best motion practice which will produce least fatigue in the operator, and give a more satisfactory product in a shorter time.

Principles of Motion Economy.

From such detailed studies the following general principles of motion economy have been formed and these can be applied, without the accurate measurement, where through investigation is not warranted :

(1) Every new system of movements should aim at establishing a rhythm, as this not only lessens the fatigue, but reduces the time of the operation and increases the operator's satisfaction.

(2) All movements should involve as few members of the body as possible, without interrupting the natural rhythm.

(3) An operator should work with symmetrical movements as much as possible, so that he can maintain a balanced posture and eliminate all uneven movements. For example, in Fig. 1 the old method is shown where the operator is holding a plate with the left hand while she assembles rivets with her right hand, thus having her movements uneven, and her left hand doing no useful work. Fig. 2 shows the new method where the plate is held in a slot in the jig, and both hands assemble the rivets in the plate. This and the other improvements on this operation enables the operator to assemble 180 plates an hour, instead of the 90 she did by the old method.

(4) In developing the new system of movements every available

Fig. 1.

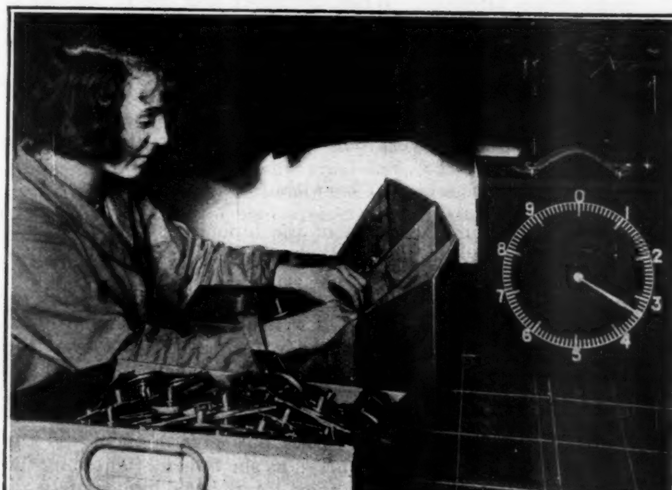

Fig. 2.

advantage should be taken of the anatomical structure of the part involved. In hand movements the work should not be restricted to the thumb and first and second fingers, the palm of the hand and third and fourth fingers should also be used whenever possible. An example of the application of the use of this principle has been found in several investigations where a bearing screw has to be adjusted and a nut tightened to lock it into place. In the old method the operator adjusted the screw with a driver, and after replacing it on the bench picked up a spanner and tightened the nut. A box key was devised which ran smoothly over the shaft of the screw driver, the screw was adjusted and the box key slipped down the shaft to tighten the nut. The use of this is very simple, the palm, second, third, and fourth fingers use the driver, and the thumb and the first finger turn the box key. Thus the one movement of the hand combines the work of both tools.

(5) All material and tools should be placed within areas of easiest reach. When considering hand movements there are two working areas, a normal and a maximum. The normal is for all movements of hand, wrist, and lower arm, in this case the easiest area for the right hand is within the semi-circle described on the bench using the elbow as centre, similarly for the left. The easiest area for both hands is the centre segment where the two semi-circles intersect. When the upper arm has to be used it is necessary to consider the maximum area, when the shoulder is the centre of the circle. Thus work should be laid out so that the bins into which the right hand goes are in the right segment, and those for the left hand in the left, and jigs and fixtures used by both hands in the centre segment. This means in practice that the work bins are in a semi-circular formation as in Fig. 2.

Hand tools should also be within areas of easiest reach.

(6) Advantage should be taken of the human tendency to form habits. All material and tools should be placed in exactly the same position each time so that there is no unnecessary fumbling, and also the eyes do not need to move from the work on the jig where they are focused. The work bins should be so designed that the parts all slip down to the front, so that the last part is picked up from exactly the same position as the first. Also all tools should be so placed that they are always in the position in which they have to be used. In Fig. 3 the spring return yankee drivers have box keys in them and the operator uses one with each hand, as she finishes tightening the nut, she releases them and they jump back immediately on

the arms to a set position. If they were only on a spring they would jump away, but would oscillate and not be in a set position when she wanted to use them again.

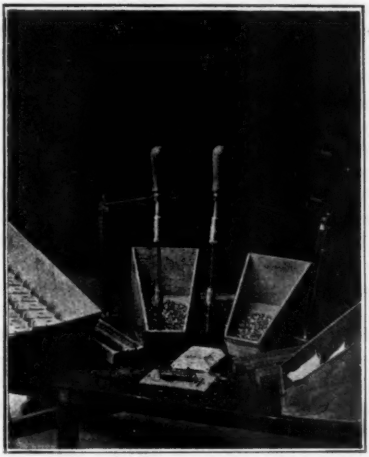

Fig. 3.

Training.

When the Motion Study Investigation Section began there was much discussion about the place where the operators should be trained. There was a general feeling that the training should take place at the bench on which the operators were working in the shops. This was originally tried out, but found to be entirely impracticable, as the old influences were too strong and also the operators too shy of the publicity to obtain satisfactory results. There is now a special training section where all investigations take place, and where the operators are taught.

The operator is brought into the section and shown the old method pictures, the charts, etc., or where these have not been taken, the faults are shown to her as she does the work, and the new method is explained in great detail and the improvements pointed out. Then the investigator demonstrates the movements and allows the operator to start while he watches carefully and corrects all wrong movements. In organisations where there are a number of operators on one job, group training could be given by demonstrating the new method on the movies after one operator has been trained on the new method and her work filmed.

When considering the adjustments of the operator to the new method there are various difficulties to be overcome. There may be the antagonism of the workers as a whole, as well as the difficulties of teaching the individual the new series of movements. This general antagonism is considerably less than is often supposed, and is really very understandable. Workers seem to have the constant fear at the back of their minds, that any change or improvement may mean unemployment for them or their co-workers. They have realised, after long experience, that they have to accept the replacement of labour by machinery as inevitable, but in the case of reduction of movement by the study of an individual's work methods, they tend to feel that they can prevent the change taking place by pitting their own wits against what they consider the madness or fad of the investigator. However, when it has been proved that the company is not using motion study as a weapon for victimisation, and that no one is discharged as a result of improved methods, the feeling of resentment gradually disappears, to be replaced by interest in the new methods.

Even when the operator is very willing to co-operate there are still difficulties in teaching the new series of movements. Perhaps one of the hardest tasks is to break down the established habits which have often been acquired with considerable personal effort. Sometimes it takes several weeks to counteract the habits formed, other times only a few days or even hours ; this largely depends on the adaptability of the operators. Teaching the operators to synchronise the left and right hand movements is the most serious problem. Many trainees say that they cannot use their left hand, but this prejudice is overcome once they have become accustomed to the method, and there has never been a case in which an operator, when given the chance, has chosen to return to the old method in preference to remaining on the new one.

Establishing New Methods in the Shops.

Once the desired efficiency is attained by the particular operator, the job has to be established in the shops. The bench is laid out according to the findings of the investigation, and at the same time the transport of material to and from the bench and between operations is reduced to a minimum. Instruction sheets, showing the actual movements and the positioning of all tools and material, are given to the foreman so that he has a precise detailed record of all phases of the operation and the output which may be expected from the operator.

Motion Study applied to Tools and Material.

So far motion study has been described as applying to the actual movements of the operator, but it should also include tools and

material, the two other factors in production. In the past, jigs have generally been designed for easy loading and unloading, but often not for two-handed work, this should always be borne in mind by tool engineers, as loading and unloading a jig with both hands, cuts down idle machine time. When designing jigs for assembling parts the aim should always be to reduce the movements of the part as much as possible. Motion study jigs are often equipped with mirrors and magnifying glasses for this purpose and are also mounted on turn tables so that they can be used at all angles.

These ideas can also be applied to all aspects of the question of material; the actual type and quality of the material is a very important factor in the final assembly. It has often been found that with very little additional expense a great deal of time can be saved by a slight modification in the design of the material. If draughtsmen have some idea of the principles of motion study it is often possible for them to help considerably by remembering, while drawings are being made, that the apparatus is going to be assembled under motion study methods. In fact, such assistance can be carried right through an organisation if everyone is encouraged to think in terms of motions and become "motion minded."

When the system was first introduced into Metropolitan-Vickers four years ago, it was recognised as essential that this "motion mindedness" should be spread as much as possible through the whole organisation. Series of lectures were arranged for different groups of engineers, draughtsmen, and foremen, and these have proved most successful. Throughout the whole factory there is evidence that everyone has at least a little knowledge of the subject, as the glaring instances of bad movements, which were quite common practice a few years ago, have disappeared.

Results.

It is impossible to measure the results of these lectures and the small jobs that are continually being put right along motion study lines by everyone in the organisation, but for those investigations actually completed by the Motion Study Section, the average increase in the daily production per operator in 70 investigations has been 173 per cent. This does not mean the speeding-up or driving of the operators, but is due entirely to simplification of the processes, and elimination of all unnecessary movement.

Discussion.

MR. C. H. POWER (Chairman): Personally, I have not had any experience in the highly scientific form of motion study needing so much apparatus to produce results, as described so ably by Miss Shaw. My experience has been more with the use of the stop watch, and it is surprising what tremendous improvements can be made after careful scrutiny and close analysis of the results obtained by such a simple method. My firm have been practising motion study by this method since 1914, and during the intervening period so much data has been collected that on any new job one can predict, to within very close limits, what the production time should be. It is surprising what an amount of saving can be effected by close investigation into the right type of labour and the proper preparation and handling of materials along with the service necessary to see that both are available at the right time and in the right place. Miss Shaw quoted the words of a French thinker who drew attention to the fact that we spent a tremendous lot of thought in obtaining the correct materials and paid but little attention to the human material. In the case of my firm, it has been our practice, whilst giving very careful consideration to the material we use, to give infinitely more time and thought to the selection and training of our human material, with a result that our labour turnover is exceedingly small. Nothing makes for inefficiency more than a floating staff. A further point brought out was, that when embarking on these scientific investigation methods, the very first thing to do was to give consideration to your staff. It is quite natural that they will not all immediately take to the new ideas; they are apt to feel that it is their job that is being messed about, also, that this new move is a condemnation of their efficiency of control, and usually it is the most efficient of the staff who are the most stubborn. I think it is important to remember that before the full co-operation of the staff can be gained it is worth the time and trouble to take them into your confidence and let them know exactly what you are doing and what you expect to achieve. Let them know that what you are doing is not a condemnation of their methods of control; that nobody will be blamed and that you want and expect their willing help to attain the end in view. One must not hurry these things; it is wise to go slowly. I speak from experience, having gone through this process of change from the old methods of production control to the new. I agree with Miss Shaw that the best place to instruct the workers is to take them in a section apart; this tends to eliminate self-consciousness and makes for more consistent and regular records; it also banishes the feeling that they

are setting too hot a pace for their fellow-workers. With regard to the possibility of the new methods so improving production that there is displacement of staff, it is our practice whenever we develop improved ideas or machines, to guarantee to the displaced labour another job at the same rate of pay.

MR. H. SHAW: We have always designed jigs so that the work could be inserted and removed as easily as possible, and located as quickly as possible. We have always endeavoured to place tools as near to hand as possible and have arranged for as little transport of material as possible. We have done these things, but have not called them "motion study" but "common sense." I think there is quite a lot in rhythm of movement. I recently had an example of this in a small works where the meaning of "motion study" is not known. A workman was operating a hand forge and I noticed occasionally when he had finished forging, he cut one in half with the cutter. When I asked him "What is the matter! Why have you scrapped that?" he said "There is a defect in it." "Didn't you notice it before the finish of the job?" "Yes," he said, "but I didn't want to spoil the rhythm." With regard to the chronocyclegraph, I do not quite see how you can tell the length of movement. If you get the hand moving directly towards the camera, you would only get one spot and no length of movement. If moving at an angle of 60 degrees it would appear to be moving half as fast as if it were moving parallel with the film.

MISS SHAW: I think I have been misunderstood. We use a stereoscopic camera. The photograph is no use to us unless it is in three dimensions. Usually we can see it quite accurately enough in an ordinary stereoscopic photograph, but if not, we do sometimes expose the film twice, first against a cross-sectioned background with two axes, and then use these for reference. As regards the question of rhythm, perhaps I did not stress the word "rhythm" but all our work is based on that in order to develop the easiest and most practical method. It is the basis of making all movements and the reason why they should be simultaneous and in opposite directions. As regards common sense, as I said in the paper, each application is based on common sense, but in my investigations so far I have found that it is one of the most uncommon qualities that one finds in factories.

MR. CROOKE: Obviously, motion study, in whatever form it is pursued, has one ultimate aim: i.e., results. The lecturer stated that 69 investigations were carried out in three years and gave increased efficiency or output of 173 per cent. In surgical operations one often hears that the operation was successful but the patient died. How does this apply in the motion studies? Does it cost more to investigate and improve than is justified by actual saving?

Miss Shaw: We never make any investigation until we have costed what our saving would be against the cost of the investigation, but we find that we can always justify what we spend on the investigation. On the whole our expenses never amount to 10 per cent. of our savings. Each individual section of the investigation has got to pay for itself before we touch it.

Mr. Crooke: When reckoning the cost, is the cost of the supervisory staff that controls "motion study" counted in?

Miss Shaw: We do reckon it in the final cost, as well as individual costs of the jigs and fixtures and things like that.

Mr. Fraser: I can back up everything Miss Shaw has said tonight. In connection with fatigue, I would just like to get a general expression of opinion as to what the usual reply is from people who have been put through this motion study operation. What percentage generally feel more or less fatigued at the end of the day? I know from experience there is a lot of opposition when motion study is first taken up. Miss Shaw made a statement that, generally speaking, most people after some little time take to it and become part of it, but I think some definite figure would be interesting; it cannot be 100 per cent. efficiency, there must be some operators who have proved inefficient. I would just like to add that I thought some of the films were rather too short.

Miss Shaw: I am very glad to hear the criticism that the films were too short. It is one of our biggest difficulties in showing the films. For ourselves, we get so tired of them that we think them far too long. It is difficult for us to realise what an outsider is seeing—how much they are able to take in.

On the question of some operators not being successful, we, of course, always endeavour, when we are studying the operation, to choose the very best operator that has ever done the job before, so that we make an initial selection, and that does cut out the question of failures. We have had one or two turned down. I think there have only been two in investigations we have made so far. One was a girl brought into the factory and trained from the beginning, but she obviously was not suitable; her movements would never have been quick enough. The other case was of a girl who had been brought into the section, but after having been in for some time she was sent back and put on to another job. I cannot remember any other case where the operators have not been satisfactory. On the question of fatigue, it is one of the most difficult questions for the industrial psychologist. There is actually no measure of fatigue. There is a measure that the physiologists have been developing, but it is not practical at the moment. As regards the question of output—the falling output at the end of the day—that is really no measure of fatigue. We find, usually, that instead of falling it goes up. It is nearly always at its highest in the last hour of the

day. That does not really mean that the operators are not fatigued ; it is really the incentive to make up their wages. What we endeavour to do is to eliminate all causes of unnecessary fatigue. We feel by doing this that we are probably getting at fatigue in the best way we can until we can get some actual measure. As regards the operators themselves, when we have finished the investigation they all feel that they are less fatigued, due to the rhythm of the job, and doing the work with both hands evenly. The operators do appreciate that, once they have been trained in it.

A Speaker asked a question regarding the lay-out of a factory. In the case of automatics nice straight lines are usual, but from a " motion study " standpoint, is it not desirable to have the machines in semi-circles around the operators ? Whilst it is relatively easy to teach an operator to use both hands simultaneously, how did Miss Shaw help the operator to concentrate her thoughts on the two parts at one time ? Regarding these 100 per cent. gains that have been made, has Miss Shaw reduced the piece-work price of the operations ?

Miss Shaw : The length of time to analyse a film depends entirely on the complication of the film. Some jobs are very complicated to analyse. As regards concentrating their thoughts on both hands, wherever possible we give both hands exactly the same thing to do, so that they do not need to think separately. You may have noticed on the first "movie" that the operator was lifting the left hand slightly in front of her right hand. It was taken three hours after the girl was shown the new method and she was still concentrating on her left hand. We had been trying to teach her very intensively. Now she can work quite evenly with both hands. Usually the operators do not need to think about what they are doing with their hands ; it becomes automatic, and our aim is to make it become automatic. You do want your machines in circles round people. In fact, the factory in nice straight lines is just the thing we are up against when we are improving. We always want them to be in a semi-circular position, as it is better from the movement point of view for the machines to be grouped around the people operating them. Other considerations have to be taken into account, however. Our comparisons are based on our piece-work prices when we have finished. We do not consider that we have got the output until we have got the piece-work price settled.

Mr. F. W. Shaw : I can well imagine that the girls after working eight hours a day going through the numerous movements with their hands, shoulders, feet, and legs will get over-tired. I have had that experience. I have done a fair amount of motion study but without the aid of a cinematograph and without the aid of Therbligs—just with an ordinary stop watch, and I think there must be over-fatigue with the number of hours of work at a speed

commensurate with anything we have seen on the films to-night, unless the operators are given plenty of rest between. As an example of this I will mention the case of a machine operator on a simple lathe, where the feed motion was by hand and where the chuck was operated by hand. In order to improve the output a helper was brought in to take the piece from the bin, hand it to the operator, who chucked it and performed the various operations, unchucked it and passed it back to the helper, who put it back into the tray, with the result that the time was reduced from five hours to two, but at the end of the two hours the operator was exhausted, and the helper also. Why? By reason of the concentration that they had put into that job—mental concentration as well as physical. However these girls can last out eight hours a day is beyond my comprehension.

MISS SHAW: We all agree that hours are far too long in the factory, just as much for brain workers as for hand workers. We find that most operators, unless they are on a continuous belt, where they cannot stop, are not keen on rest pauses. We have tried breaks with operators who were trained and also find that once they get settled on the job they do not have to think half as much. They begin to do it automatically and, therefore, do not have the tiredness resulting from concentration. They do not seem to feel any particular tiredness due to concentration at all. In fact, I think fatigue is considerably less when they get their movements automatic; and our aim is to develop this habit.

A SPEAKER: When you have a job which involves a definite decision of mind, then I cannot see how you can do two things simultaneously. A thing is either right or wrong, and the mind can only decide one thing at a time. Rhythm would be better than simultaneous movement.

MISS SHAW: When it is a case of an actual decision we do not expect the operators to make a decision with each hand. There are very few operations that come more than perhaps once in a cycle that require an actual decision, especially in small work. When a definite decision of that nature is required, we certainly arrange for it to be done singly.

A SPEAKER raised the point of cutting out some of the movement before having the first film taken in order to get nearly the results that are now obtained. The same speaker mentioned fatigue on monotonous operations and how it might be minimised by instituting suitable rest periods.

MISS SHAW: In regard to the question of film analysis, I said we use such analysis as an engineer uses a micrometer. None of the pictures you have seen to-night have been taken to be used for the Therblig analysis; they have all been taken as illustrations. Actually, when we take a picture from the point of view of analysing

the elements of movements, it is too complicated to show in a lecture. So the movements you have seen to-night of the old and new methods have all been taken for demonstration purposes. None of them have been used for detailed analysis. We use them to train our investigators in observing movements. As regards rest pauses, in some cases they are definitely beneficial. As I said, we have them on continuous processes. It has been found that rest pauses do not make any difference to the output at all and operators are not particularly keen about them. I think it depends entirely on what the job is and how accurately the rest pauses are worked out. There is, of course, a much greater possible output with short periods of work and rest pauses, but then that means actual muscular exhaustion, which in none of the operations I have shown to-night is the case.

Mr. Davies: We have all got to realise that whether it is a question of " motion study " or " common sense " it is there and has got to be taken notice of. It is a question of certain methods of dealing with production which cannot be ignored or someone will take our jobs from us. Regarding the question of fatigue, I consider that there is most fatigue when you are standing perfectly still and there is no motion at all. On one particular job shown to-night I really think the man would be better bending his back and picking the plates up—I am speaking, of course, from the point of view of the man and not the output.

A Speaker: With regard to the length of the study, Miss Shaw says a cycle of time is four minutes. In our factory it is sixty minutes. The idea behind this, apart from fatigue, is that no operator, however well versed, gives his normal effort in a short time. He is apt to go too fast and fatigue too quickly and then endeavours to go back to normal speed. If you take a short time at a greater effort you take no account of fatigue, while towards the end of the operation fatigue is creeping in and you find that the operator has made a greater effort than he should have done—with four minutes you cannot foresee such circumstances. How is that overcome in the final setting of piece-work ?

Miss Shaw: We do not set piece-work from the " movies." We limit it to four minutes as it is the only length of film we have. Sixty would be extremely expensive. We do not use these times for fixing the rates ; these are all fixed in the ordinary way after the study is finished. We do not worry very much about time when we are taking the study, apart from simultaneous movement. Reduction of time always takes care of itself.

As regards getting a good example with the " movie," we always warn the operator well ahead. When first starting the motion studies I have waited about an hour before a girl has settled down to a job.

PRODUCTION RESEARCH: DISTORTION IN CASE-HARDENED GEARS.

Paper presented to the Institution, London Section, by A. Roberts, A.M.I.P.E.

IN presenting this short paper it is not my intention to deal with the distortion that takes place during the heat treatment process, but rather with the troubles that arise during the manufacturing side and make the machining rather difficult, due to heat treatment distortion. The subject is centred around the manufacture of automobile gears which have to be case-hardened and are inclined to distortion.

For the convenience of the meeting, we will take a case with which the author had to deal, namely, a sliding wheel and main shaft. The main shaft originally was made from 3½ per cent. Ni Steel, heat treated in bar form before machining, and gave a Brinell impression of 3.8 to 3.6; the tensile strength was not less than 50 tons per square inch. The gear being made from case-hardening steel (nickel-chrome-molybdenum gear steel), when hardened gave a scleroscope reading of 75-85, and had a core strength of approximately 90 tons per square inch.

The main shaft was machined from the heat treated bar and turned complete on the bar turret, leaving for grinding all over. The spline diameter was ground to size and one diameter ground to suit the collets of the spline milling machine. The splines and keyway were cut, the splines being left for grinding to finish sizes, the pinholes drilled, and the splines, diameters, and taper ground to finish sizes. No trouble was experienced with the machining of this component, but the sliding gear which worked on this shaft presented a very different proposition as the spline bore was required to have a hard surface, and as no plant for finishing this bore after hardening was available, it was impossible to correct the distortion. The practice in the shops at the time was to machine the bore and face of the gear blank for broaching. This was then broached, leaving the final broach for pulling through after carburising, as it was considered that the heavy distortion was caused by the high temperatures used for carburising. After this the gear was machined complete locating off the spline bore for all operations. The limit dimensions and tooth form were left for final grinding after hardening. The gear was then carburised and normalised (close annealed, forty-eight hours oil furnace) and the final broach

pulled through to size the bore ; the gear was hardened off and the grinding of the limit dimensions and tooth form completed. It was found by this method that the spline bore was distorted to the extent that the parts would not assemble and, therefore, it was necessary to hand stone the splines before the parts could be assembled and made workable. This made the method far too expensive.

Our jig and tool department, however, stepped into the breach with a grinding spindle driven by compressed air. This was fixed up on a Flather automatic gear cutting machine and the distortion was removed from the spline bore by grinding. This proved a big saving over the previous method, but was again too expensive.

The problem then was how to overcome our troubles, and after various discussions, it was decided to try reversing the conditions—that is, we should have a case-hardened shaft and a soft bore gear (splined), both components being made in the gear steel. By this procedure we anticipated that we could again grind the shaft to final dimensions after hardening off, but the gear still presented difficulties.

The method adopted was to drill, bore, and face the gear blank for broaching. The bore was broached round and splined, leaving the last broach for sizing after hardening. Then the blank was machined all over, leaving all the important dimensions for final grinding after hardening, all operations locating off the spline bore. The bore and end faces were then copper-plated to prevent carbon penetration and the gear was carburised and hardened off, the final broach being pulled through to size the bore. All important dimensions, including the tooth form, were ground to final dimensions, again locating from the splined bore. Here also, although we produced a correct gear, trouble came along in the form of broken broaches when performing the final broaching operation. This was caused by hard spots or carbon penetration through the copper plating. On further investigation it was discovered that the sharp edges and corners of the spline bore were causing the trouble, as the copper plating did not always adhere to these. This set the author thinking and he came to the conclusion that the best method would be to produce a gear by carrying out the complete broaching operation after hardening and grinding the important dimensions to size.

This method raised certain questions as to its advisability, the risk being considered too big to take, as the broaching would be required to be absolutely true. However, it was decided that a trial be given and several batches were produced with success. The procedure adopted was to machine the gear blank all over, leaving the important dimensions for final grinding, the plain bore and end faces having a double grinding allowance. The

gear was copper plated in the bore and on the end faces only; the gear was then carburised and hardened. The bore and end faces were ground to suit the barrel diameter of the broach for location. This operation also removed any slight surface penetration of the carbon. Then the gear was ground on the diameter to suit the fixture which located the whole on the nose of the broaching machine.

This method gave no greater error than .003 inch, which proved to be quite successful. The final operations were completed by grinding, and a correct gear was the result. One gear was sectioned and tested in the laboratory and found to be an excellent job. A section of this is available for inspection and it will be noticed that the carbon penetration is very even, no carbon having entered the bore.

It was found that a slight normalising operation of approximately twenty-four hours duration ensured that no trouble was encountered during the broaching operation (this applies to both methods). I might add that this operation was carried out in the electric furnace after the first quench, the idea being to exclude any traces of carbon.

The author would like to add that it is essential that the copper plating is a perfect job, otherwise if hard spots are encountered, one can realise that the broach costs will be high.

It may be interesting to members to hear how we carried out the copper plating. As only the bore and faces were to be coppered, it can be realised that it was necessary to protect the outer portions of the gear and this was achieved by having containers to hold two gears each. The container had a hole in the base approximately the size of the gear bore. First, a rubber washer was placed at the bottom with a hole to correspond with the face diameter. The first gear was placed in the container, then another rubber washer of the same dimensions as the first, and the second gear was placed on top, followed by another washer. The whole was bolted together with a copper bolt, this being used as the anode. The container was then immersed in the plating vat to a depth that allowed the solution to come up to the height of the gears. This ensured no solution reaching the outer surfaces—in other words, the bores of each pair of gears formed the plating area, the plating period being approximately of two hours duration which gave a thickness of .003 inch. This method of copper plating is very successful and is the standard method employed in the factory to-day.

PRODUCTION RESEARCH: SPEEDS AND FEEDS IN PRESS WORK.

Paper presented to the Institution, London Section, by L. Barker, A.M.I.P.E.

THIS subject covers a very wide field, and the amount of of applied research or study expended thereon determines the cost for which articles can be produced, and often the possibility as to whether the proposition is an economic one. It is probably safe to say, when one considers the range of press work exhibited at the one-price stores, the variety of household equipment and even to details of the motor car that one hears so much of at these gatherings, that no branch of production engineering offers such scope of interest and economic possibilities as press work. The terms speeds and feeds do not bear quite the same relation to one another in press work as they do in ordinary machine shop language, as in press work it is the feed that is the chief factor governing the ultimate speed of production. The method of obtaining the ultimate speed or total time taken to produce a given article may be approached in two distinct attitudes of mind. Firstly, the policy of performing as many operations as possible in each tool or operation, the aim thus being to make the finished article, if possible, a single operation. This method, except in very simple cases, almost inevitably results in having tools which are of complicated design, are expensive in first cost, and take a long time to make and try out with delay in getting the product in production. Secondly, the opposite method of splitting up the total amount of work into simple operations and then making simple and comparatively cheap tools, may appear at the planning stage to perhaps be uneconomic. Estimates of initial tool cost and production times should be made and checked against the total estimated production cost of the full quantity to be made. One cannot lay down a fixed rule here or generalise too much. Each case can only be taken on its merits, beyond the point to say that the result of experience strongly suggests that a decided bias should be exercised in favour of the second policy, chiefly because complicated tools are much more likely to break down, and when they do they take longer to repair, which means money, whilst the whole of the production is held up. The simple tools do not require the same upkeep or maintainance and, therefore, the production flow is less likely to suffer interference. It is not proposed to deal with mechanical feeds such as carrier bar or hopper feeds, as these generally resolve themselves

into single-purpose machines for dealing with a continuous production, but rather to indicate a few of the considerations bearing on the time factors for production of substantial quantities of a recurring variety, which is no doubt the case in the majority of factories turning out medium sized articles.

It is assumed that the best policy is to start by having good quality tools mounted on pillar die sets. It is worth mentioning, in the author's opinion, that the pillars, wherever possible, should be disposed diagonally if only two are used, and also (although this point does not appear to have received due consideration, and is somewhat an open question) fixed to the top punch holder with the bushes in the bottom. This method facilitates sharpening or grinding as the die can be ground in position without the interference of the pillars.

Tool Design.

It is at the designing stage that the method of feeding or operation of the press tool, which is the chief index of the speed, requires the most careful thought in collaboration with the tool-maker and the press shop foreman or operator. It is admitted that many operations called for in the design or shape of the part, present such difficulties of accomplishment by a reasonable design of tool, that there is a tendency to miss the point as to how long it will take the operator to feed the tool and complete the cycle of operations. It will often be found that to spend a few pounds more than the bare necessity by incorporating automatic stops, knockouts, provision for air ejection or special pilots is a profitable investment. On the other hand, a complete change of method will sometimes be found the best way.

The safety of the operator should also receive early consideration, and it is often found that the fast operating tool is the safest. It is taken for granted that whenever the operator's hand need to come within the danger zone, a guard approved by the Home Office should be used, and in this connection the author has found that the latest " Udal " long pull type embodies the result of much research on this subject as a high safety factor is obtained, without undue slowing down of operation or fatiguing the worker. A press guard will be found in practice to need a great amount of care and vigilance to see that it is kept in good repair and correctly adjusted for each individual set-up.

Blanking Tools.

A blanking tool with a fixed stripper and fixed stop, which has the advantage of allowing of the use of a short stroke press if one is available, can be operated very fast by hand when the operator has become used to the feed and movement necessary to catch each

stroke with the press running on repeat. Obviously, if a short stroke press is not available, this type of tool can be used on a long stroke press, but not to the same advantage, as the punches are not supported during the whole of the stroke. In this connection one or two adjustable stroke presses in the department are to be recommended. A production of from 3,000 to 4,000 per hour depending on the speed of the press, length of part and whether strip or coil stock is used, is quite commonly experienced with a tool of this type. The inherent disability of this type of tool in the ordinary way, is that the operator is unable to see the die, and is therefore working somewhat blindly with detrimental results to the punches when loose blanks or misplaced strip happen to be on the die when the next stroke takes place.

For ordinary blanking work, the best combination between feed and speed is to provide for a spring stripper carried on the top tool, a guide for the strip at each end of the tool and an automatic stop, so that the die is visible and the operator can see exactly what is taking place before each stroke. The blanks go through the bottom die. A somewhat better blank is obtained than that given by the previous type of tool, and the production rate is as great as the press will give when run on repeat.

Compound Blanking Tools.

For blanks from thin metal that need to be clean and flat, and where holes are required to be located precisely relative to the outside of the blank, the general practice used to be to provide a sub-press compound tool, having the punch proper at the bottom and the die on the top, or vice-versa, but the blank was invariably forced back into the stock by spring pressure. Except in very special cases it was generally rather difficult to get the blanks out of the stock quickly and automatically, and sometimes they came out of the stock on to the die and had to be removed by hand, and if not noticed and removed, caused damage to the die on the next stroke. All the advantages of this type of die can be obtained with a much faster feed if a fixed pin stop on the die is used, and instead of the blank being ejected from the die back into the strip by spring pressure, it is carried upwards by the top tool and is ejected by a pad held inside the die and around the perforating punches. This pad is connected to a knockout pin that extends upwards through the shank of the top tool, which is operated on by the knockout bar of the press, at the top of the stroke, thus ejecting the blank which falls clear. If the press is inclined it will quickly slide to the back, and the die is clear ready for the next stroke. A good production rate of 1,500 to 2,000 per hour can be obtained in this way. It is the author's experience that dies of this nature if mounted on die-sets generally cost less than the more

orthodox types mentioned, with the great advantage that, if the location of the holes to the outside of the blank are correct when the die is first made, incorrect blanks cannot possibly be made through any fault of the operator, although the speed is somewhat less. It is sometimes found that if the air pipe is connected to the top tool and is set to give a jet of air at the precise moment when the part is being ejected, at the top of the stroke, a quicker feed can be obtained. Of course with these tools the perforating punches should be in the top, thus allowing the perforations to be automatically ejected through the die.

Blanking and Drawing.

To mention just one method of blanking and drawing by hand feed, and the layout that enables a production of 3,000 per hour to be obtained, is perhaps of interest. The coil of stock is placed at the back of an inclined press and is pulled forward by the operator. One blank and draw is made, after which the coil is pulled forward over a fixed pin stop, and then pushed back for location of the next blank. For a moderate size of draw the action of pull and push can be operated sufficiently quickly to synchronise with the press running on repeat. A knockout is incorporated in the punch, and as this operates at the top of the stroke an air blast is directed on the falling part which quickly directs this down a shoot at the back of the press. It is this point of getting the part away quickly by air that enables the press to run on repeat.

Automatic Feed for Blanking.

The automatic feed for blanking tools is generally either roller or gripper feed. Roller feed attachments fitted to standard presses enable a good production of 3,000 to 4,000 per hour of plain blanks or simple perforated blanks to be obtained. Where there exists a sufficient quantity of this class of work which can be supplemented by somewhat more involved forming operations whilst in the strip, a special roll feed automatic press becomes a proposition. American practice in this respect is typified in the examples of the Henry & Wright dieing machine and the Bliss high speed press.

The Henry & Wright machine is unique inasmuch as the crankshaft is below the bed of the press and the ram is pulled down at each stroke. The advantage claimed is a low centre of gravity of the machine which permits high speed running. There is a strong temptation to attempt to complete too many operations in one tool in order to obtain a part finished complete from the press at each stroke, and so complicate the die. A certain amount of forming with this object in view can be done, and a production of from 6,000 to 10,000 per hour obtained, and it is surprising how a press

of this nature will deliver the goods if the tools are suitably designed and made and the set-up is carefully carried out. One or two examples of what can be done at a single operation can be seen. It cannot be too highly stressed that the tools for any type of automatic press must be as near as possible 100 per cent., and when being tried out for the first time, it is invariably necessary to embody various points such as spring ejectors to facilitate travel of the strip. With spring pins on the die, pilots on the top, and a spring pin in the punch itself, the idea seems to be to keep the strip floating in mid air and only in contact with die at, or near, the bottom of the stroke, when the rollers are released. These same remarks apply to the tools for the Bliss high speed press which is of more orthodox design with the crankshaft at the top. This press will run up to 350 strokes per minute, and is an example of the present day tendency to design presses for higher speeds. We also have British presses that have been designed to run to high speeds.

The gripper feed type emanates chiefly from Germany, the Schuler and Weingarten being well-known examples. This is a positive feed obtained by two pairs of gripper feed bars disposed each side of the tool or centre of the press and caused to reciprocate the exact distance of the pitch of the job in hand. The strip is never released as one bar each side releases and travels backward ready for the forward movement, whilst the other is stationary and gripping during the actual blanking operation. An accurate and consistent feed can be obtained, and although speeds as high as the roller feed presses cannot be obtained, they will function up to 150 strokes per minute according to the length of feed and type of job in hand. A coil rewinder or scrap cutter that takes care of the scrap strip as it leaves the press is a standard fitment on all automatic presses and leaves the operator free to attend to more important duties. Incidentally, one operator can attend to more than one machine, especially if the parts being produced are not complicated, in much the same way as a setter runs a battery of auto screw machines. Remembering the speed of production mentioned for automatic presses, it will be noted how low production costs will be. The parts can also be stacked or threaded on rods as they leave the press, thus facilitating handling for assembly or subsequent press or finishing operations.

Hand Feed for Forming Operations.

This section accounts for the bulk of work in most press departments, and therefore will justify study of feed and speeds. The result of experiments over a long period demonstrates that the chief factors making for high production speeds are :

(*a*) Synchronised movements on the part of the operator when feeding, and
(*b*) A quick ejection.

Hand Feed and Hand Ejection.

As regards (*a*) handling when feeding, it will be found a good method to provide a receptacle or shelf in front of the press on to which the operator will place a convenient quantity of parts. With his right hand, he will place parts on the die, and as soon as the punch is on the up-stroke and the guard is open, he will take it off by the left hand. Before the part is taken off another part is in the right hand, ready, and is placed in position the instant the previous one is taken off. An operator that has familiarised himself with these movements can attain a production of about 900 per hour. This is where, from the nature of the work, the parts have to be taken off by hand.

Hand Feed and Auto Ejection.

It will be found, however, that the majority of jobs can be removed from the die by semi- or fully-automatic means. This brings us to (*b*) ejection, which, incidentally, is the chief factor which is generally capable of improvement, and the first consideration should always be the provision of an air blast. This is provided by the compressed air line being brought to the press and connected to a valve which is operated by a cam fixed on the crankshaft. The pipe is led from the valve to a nozzle to be used on the die. This cam or trip can be adjusted to give a jet of air at any point of the stroke of the press. For the case in point, it will be arranged to give this jet on the side of the part at the moment the punch has left it on the upward stroke. Sometimes it is necessary to provide a groove in the die so that the air can thus lift the part free and project it sufficiently to the rear so that the inclination of the press or an inclined chute will allow it to slide into a box at the back. The operator will then only need to feed and can therefore increase his output to about 1,200 or more per hour. Sometimes it is an advantage to remove the finished part by deliberately allowing the punch to lift it clear of the die when the knockout ejects at the top of the stroke so that it will slide out of the way, due to the inclination of the press. Another provision making for speed is to provide fingers to pick it sufficiently high in the air to allow it to slide clear.

Chute Feed and Auto Ejection.

Simple forming operations where the accuracy required is not so great, gravity feed down a chute can be used, and if the press is inclined a fast production can be obtained with the added advantage that the operator is not subject to any danger, i.e., a completely enclosed box guard can be used. In a general way, this happy arrangement is the exception and it will, for the most part, be found that the component must be placed definitely in

position on the die. This, of course, slows up the operation and also raises the questions of guarding for safety of the operator, and ejection or moving of the part from the surface of the die. The above embodies points that can perhaps be said to be obvious, but it is a fact in experience that unless one sets out to attain the best conditions for efficiency, the eventual procedure will generally be found to be wasteful in time and effort, with the result that the cost is increased beyond that which is truly economic.

PRODUCTION RESEARCH MANAGEMENT.

Paper presented to the Institution, London Section,
by A. J. Parker.

UNDER this general title, I want to raise a number of problems connected with the organisation and control of production research, and of getting results from research work. We use the term research in this connection not in its strictly scientific sense and yet something more creative than the mere study of methods. The *practical working limit to such research work is, to my mind, the stage of development that can be applied with profit.* First and last the test is application, and that has an important bearing on the type of man suitable for the job. He has to be able to recognise the *difference between* open-minded *pursuit of knowledge for its own sake* and the kind *practical finality* required in the works. *One* of the management *problems* associated with this kind of work is to get an *answer* from the *production research* engineer which is *complete* in itself and can be applied with profit even although it is not finality. *One* so often *hears* the *complaint* that it is not ideas that are wanting but *practical stopping places for them.* The managing director or works manager says : Find me the man that has sufficient general and commercial knowledge and understanding to know when to stop experimenting. It is *characteristic* of the kind of mind interested in research work always to see *new possibilities* growing out of the work in hand, and to overrun the stopping places. The *creative* side of the production research department's work *needs more recognition* ; it is often artistry of a high order, *but* it is only permissible in so far as it achieves the purpose of profitable production. Art for art's sake in this connection is indefensible.

That leads to an important question of organisation in research work. Theoretically, the function of the research executive or department is to make studies and recommendations regarding specific problems submitted to it, and it is the function of management to direct and control. In practice, the direction and control in most businesses is only of a very general character. Furthermore, so many of the problems with which the production research people deal grow out of their own investigations, so that it is found in many cases that the management function is very much mixed up with the research function, but it is nevertheless important to recognise their different spheres and to see that responsibility is properly allied to authority. Results from research work are often

slow and management human (we are rather apt to forget that) and if proper provision is not made for the exercise of direction and control, things drift along and a conviction grows in high places that nothing is ever done and "the man's a fool." Human nature being what it is, action is not taken until someone gets really worried about it and then there is a general row. When the storm breaks it is extraordinarily difficult to remember what work has been done. Even if standardised reports are not called for by management (and in my submission they should be) any research worker should keep a record of every job in hand and its progress. Those who do it will say "that's obvious," and those who don't will say "it's a waste of time." Still, I hope to learn something from your views on this vexed question, for vexed it is. The writing up of a log book after the job—what a lot of breast-burning and cursing there is about it! But so many problems occur that an adequate log book will repay the trouble of writing it on this ground alone.

Then there is the allied question of the presentation of findings or a suggested plan of work for which sanction is sought to proceed. It is a popular complaint that schemes are turned down without proper consideration, or that nothing is done about suggestions made. There are two sides, of course, but I suggest we confine ourselves to the side on which we might be able to do something. We can consider whether suggestions and recommendations are put forward in the most helpful way, and that is well worth doing because many a good scheme is not considered because the responsible executive has no time to wade through a mass of verbiage to find out what the suggestion is, nor will he be able in many cases to guess what really is in the mind of the writer of the three-line kind of suggestion.

The trouble about many reports is that they are not complete. It really is a very difficult thing to make a *concise* and *complete* statement; stages in the reasoning are jumped because all the detail is so familiar to the writer and seems unimportant.

Another point is that deductions are too often based on assumptions and not proof. It is not always possible to give proof because small things arise under working conditions that are not disclosed at the experimental stage; but the least that can be done is to distinguish between the proved and unproved deductions.

Then there is that dangerous spirit of optimism. I believe optimism to be an essential characteristic of the production research man, but it must be controlled optimism. What a great thing it would be if we could turn it out, then we could open out during the earlier stages and the rough going, and gradually throttle down as the final stages approached and so avoid unduly extravagant claims or estimates.

It is not of much value to raise all these difficulties without trying to say something constructive, so I offer for your criticism my own way of dealing with reports.

I suggest that a report should consist of :

(1) A summary, dealing with the following points—

(*a*) The concrete proposals.
(*b*) Object of proposal.
(*c*) Estimated result, saving.
(*d*) Estimated cost.
(*e*) Improved consumptions.

The summary should be referenced to numbered paragraphs, in the body of the report.

(2) The body of the report containing ,in numbered paragraphs, detailed stages of reasoning, separate and clear, supported with all available proof.

Obviously, the emphasis, even the number of items cannot be fixed and unalterable. I suggest what I consider to be minimum requirements. The only point to which I want to call your attention is the inclusion of " improved assumptions " in the summary. I have come to seek that information I suppose because experience has so often driven home the lesson that it is the improved things—often small things in themselves—that wreck plans. I want to know what are the unproved assumptions, and next, if they are quite wrong, would it make the plan impossible. If the answer is an emphatic yes, it is necessary at the very least to be particularly careful especially if you have to decide as a next step that they are not only unproved, but practically unprovable—it is probably wise to leave that particular problem alone.

Another question I always ask is : " Is the method or plan fundamentally simple ?—does it follow some fundamental mechanical or physical law—is it, if you like, good horse-sense ? " All sound ideas are fundamentally simple. I shall be very interested to hear of tests that others have found useful, considering such matters. A lot of it is intuition rather than thought-out technique, but I do not think it is valuable to try to analyse how we work : somewhere, sometime, it may help someone else. Now just one last thought on that—I believe you would find it very informative for the whole membership of this Institution to co-operate in an inquiry into the form of records and reports used in connection with production study and research, some very interesting principles are almost certain to come to light.

Now, I want to switch to quite another matter—personnel problems. I make no apologies for raising issues which might be closed as theoretical. I believe profoundly that we have got to do some real hard thinking about changes in relationships in

the works that are creeping upon us, if we are to avoid some nasty pitfalls.

The production research man is essentially a staff man. I use the term staff in its organisation sense to denote one who has to get results by pursuasion and not by the blind obedience of any section of the employees to his orders—he is advisory—he points the way. It calls for a much higher grade of leadership and co-operation and a wide knowledge of practical psychology. I make no pretensions to knowing anything about psychology as the qualified practitioner understands that term. I speak purely from the angle of the man who, one way or another, has to get things done. I know that, as a general rule, people do not act on the basis of reason or perhaps I should say when reason and emotion prompt different lines of action, emotion will win more often than not. I would very much like to hear the views of some of you who are engaged on research work about the difficult task of getting the foreman's whole-hearted co-operation. I see the research man standing between two forces, one, the management, to be convinced by reason that suggestions are sound, two, the shop, to be satisfied emotionally to put their backs into it and make it go.

I have listened to, and read about, the management by persuasion school. I have an uneasy feeling that too often in their thinking they adopt in "persuasion" a euphemistic term for coercion, without realising it. All I know is that under the practical stress of obtaining and maintaining output day in and day out, someone, somewhere, has to make decisions and see that they are carried out even when the whole team is not completely persuaded. At that point they rely, of course, on their leadership—on the confidence that their folk have in them.

But that takes a long time to build and the personnel problem as I see it to-day is that the staff function of production research is being applied quickly and without due regard to explaining its purpose and function to those from whom the working results must come. I am not satisfied with the answer that other functions like accounting or cost accounting have gradually worked themselves in and production research must do the same. For one thing the people in the works don't care a hoot about the organisation of accounting so long as the results of their operations are accurate and on time, but they do care very much about the organisation of production even though they may not put it into words. The introduction of production research into a works is a knotty problem. Why? I think it is because it apparently strikes at the root of the relationships between foremen and the people they lead. Remember, it is not a question of whether it does or does not, but of how it is interpreted in the works—emotion and reason. I was surprised to hear Professor Hilton talking the other night as though staff and line organisation was a universal

accomplished fact, accepted throughout industry. Again, an intellectual decision. He finds evidence of staff work and assumes it is recognised as such. It is not, but it will have to be.

I feel this is a difficult matter to make clear. It is not that the introduction of production methods mar, or of production research causes conscious opposition ; that is comparatively simple to deal with ; it is the unconscious opposition—mental opposition that arises in the foreman's mind that is the really difficult thing. You can bring him into the discussion about the work in his shop, explain the purpose of giving him expert assistance on the subject of methods, make it clear that he has the executive responsibility and authority for getting the work done—he may agree, *but* deep down inside he feels that something has been taken from him. I suppose the only answer is, that after all appeals to reason have failed, you may still obtain his co-operation to the extent to which he trusts your judgment and honours your leadership, but that, while it may be flattering, is not wholly satisfying. I believe it is a very long term problem, speaking of industry as a whole, but will only be fully solved when training for foremanship is more general and includes the study of organisation, meantime I suggest that " Obtaining the Co-operation of Foremen " is another subject upon which your Institution can make a contribution to management knowledge.

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